PRINCIPLES AND PRACTICE OF INDUSTRIAL DISTILLATION

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BY

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TRANSLATED FROM THE FOURTH, NEW AND ENLARGED, GERMAN EDITION BY

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AUTHOR'S PREFACE TO THE THIRD EDITION

In this edition the subject-matter has been completely revised, although the form of presentation has for the most part been retained. Some points that were previously left a little obscure have been elucidated; new relationships have been unveiled and elaborated, so that the equations relating to distillation now leave little to be desired from the standpoints of ease of derivation, symmetrical form and simplicity. With their aid it is now possible to calculate the principal measurements of any apparatus required for separating two completely miscible liquids by repeated vaporisation. Nevertheless the useful application of these equations is dependent upon a knowledge of the physical properties of the substances to be separated. In this knowledge there are still gaps: neither the latent heat of mixed vapours, nor the relationship between the composition of a liquid mixture and that of its vapour, is generally known. Only a few of these indispensable desiderata can be calculated, by far the most are only to be found widely dispersed in the published literature, and many have not yet been determined experimentally; some of those which were available to the author will be found in the text.

The latent heat of the vapours arising from liquid mixtures has, apparently, been little investigated, and by no means all the results that have been obtained are concordant. Latterly, the view has been gaining ground that the latent heat of vapour-mixtures is equal to the sum of the latent heats of their (non-reacting) components; and this view has been adopted in the present work. The values used in this book that relate to the composition of the vapour from liquid mixtures were obtained partly from published communications, and partly from obliging friends, to whom my thanks are due. It will be seen from the section on ammonia and water, that gases absorbed by liquids can behave as vapours evolved from them. The first part of this work contains the "theory" of distilling apparatus (if that

word is permissible), and in the second part this is used in calculating the data and dimensions of apparatus for separating a number of mixtures; for which purpose all the necessary references, results, tables and charts have been included. It is hoped that a sufficient number of mixtures has been considered: to have included more would have unduly increased the scope of the book.

In general, only apparatus used for separating binary mixtures has been considered, because this type is most often required; the theoretical foundations underlying the separation of more complex mixtures are to a great extent unknown, and, moreover, such separation frequently resolves itself into the separation of two substances. So far as appeared expedient, information concerning such apparatus has been given.

For practical reasons it was not possible to consider fully all the physical properties of the component substances, or how they vary with changing conditions inside the apparatus. Hence certain simplifying assumptions (which are recorded in the text) had to be made; but the effect of these on the conclusions arrived at is so small that for practical purposes, which must always be kept in view, it may be regarded as negligible.

So far as is known, no process for really *calculating* the data of important and widely used distilling apparatus has been published hitherto in any language. A long acquaintance with the subject, and the exceptionally fine opportunities for study and gaining practical experience afforded by the drawing-office and workshops of the firm Heckmann, in Berlin, have enabled the author to bring his studies to a definite conclusion; and for these opportunities he will always be grateful.

THE AUTHOR.

Berlin, December, 1915.

AUTHOR'S PREFACE TO THE FOURTH EDITION

MUCH supplementary matter has been introduced into this edition, both in the text and in the tables. Among other additions a detailed exposition is given of the conditions obtaining in undivided stills of rectifying apparatus and in two-compartment or partitioned stills of the semi-continuous type. In this connection the considerations include the composition of the contents at particular times, the heat required for distillation, and the question of recharging intermittently or continuously. In the treatment of mixtures of ethyl alcohol and water, the values of Gröning and Sorel, used previously, have been replaced by those of H. Bergström, whose results agree well with the determinations of Lord Rayleigh, Blacher, Margules, and Mendeléef, and are therefore to be regarded as the most accurate. A similar remark applies to Mollier's data for ammonia-water solutions.

The number of calculations relating to rectifying and boiling-columns has been increased, and these now include a greater range of finished products and of amounts of heat expended. The new matter also includes calculations relating to the separation of mixtures of ethyl and methyl alcohols, of nitrogen and argon, and of water and nitric acid. Following the formulation of Dolezalek's law, a new section has been inserted on the calculation of vapour-composition curves from experimentally determined values of the saturation pressures of the components.

These additions to the text, the tables, and the charts have made the book much more bulky, but the author hopes that they will be found useful.

THE AUTHOR.

Berlin, Autumn, 1920.

TRANSLATOR'S PREFACE

DISTILLATION is one of the most common and most important physical processes used in industry, but, like certain of its products, it gives disappointing and uneconomic results in the absence of proper control. Although there are many good books on distillation in the English language, none of them covers the same ground in the same way as "Hausbrand." His authoritative work on the mechanism or mode of action of distilling apparatus has attained the rank of a standard treatise in Germany, and in other countries those who have been able to master its language prize it very highly. For these reasons it has been decided to publish an English version for the English-speaking world. The word "version" is here used advisedly, because the translator has had before him the ideal of producing an *English* work. To this end he has avoided literal renderings as far as he was able: he has tried to obliterate all traces of peculiarly German style and construction, including the long and involved periods so common in German scientific and technical literature; and in places he has excised redundant words and phrases, which, though familiar to the ear, add little or nothing to the meaning. He has done his best to be faithful to the sense of the original, but, holding that fidelity to form must be subservient to clearness of expression—at any rate in a technical work—he has not hesitated to sacrifice the former where these two ideals came into conflict.

The number of mistakes found in the original was very large, but many were obvious printer's errors and most were of minor importance. Unfortunately, owing to the recent death of the author, it has not been possible to refer the corrections to any responsible authority in Germany.

The title of the German work, "Die Wirkungsweise der Rektifizier- und Destillier-Apparate," was not easy to render into a suitable English form. The word "mechanism," used in the sense of "mode of action," appears to be the closest approach to the German "Wirkungsweise," but being ambiguous, it was

discarded. In the title chosen the word "practice" is intended to connote the subject-matter of Part II, namely, the application of the principles unfolded in Part I to the calculation of the required dimensions etc. of fractionating columns. As the manner of treatment is both practical and scientific, it is hoped that the book will be found useful not only by the works chemist and the practising chemical engineer, but also by teachers and students in universities and technical colleges.

The translator has great pleasure in thanking his friends Dr. A. Rule and Dr. J. S. G. Thomas for many valuable criticisms and suggestions.

E. HOWARD TRIPP.

London, June, 1925.

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TABLES

FULL TITLES OF THOSE JOURNALS FOR WHICH CONTRACTIONS ARE USED IN THIS WORK

Contracted Title.	Full Title.
Abhand. Kgl. Bayer. Akad. Wiss.	Abhandlungen der Königlichen Bayerischen Akademie der Wissenschaften.
Ann. Chem. Pharm.	Justus Liebig's Annalen der Chemie und Pharmacie (now called Liebig's Annalen der Chemie).
Ann. Chim. Phys.	Annales de Chimie et de Physique (since 1914 has been separated into the Annales de Chimie and the Annales de Physique).
Ann. Phys.	Annales de Physique (ninth series).
Ann. Physik.	Annalen der Physik.
Arch. Sci. phys. nat.	Archives des Sciences physiques et naturelles.
Arkiv Matem. Astron. Fysik Akad. Stockholm.	Arkiv för Matematik, Astronomi och Fysik.
Bull. Assoc. Chim. Sucr.	Bulletin de l'Association des Chimistes de Sucrerie et de Distillerie.
Bull. Soc. chim.	Bulletin de la Société chimique de France.
Chem. App.	Chemische Apparatur.
Chem. Met. Eng.	Chemical and Metallurgical Engineering.
Chem. News.	Chemical News.
Chem. Z.	Chemiker-Zeitung.
Chim. et Ind.	Chimie et Industrie.
Compt. rend.	Comptes rendus hebdomadaires des Séances de l'Académie des Sciences.
J. Amer. Chem. Soc.	Journal of the American Chemical Society.
J. Ind. Eng. Chem.	Journal of Industrial and Engineering Chemistry (the words "Journal of" were deleted after 1922).
J. Chem. Soc.	Journal of the Chemical Society.
J. Physical (or Phys.) Chem.	Journal of Physical Chemistry.
J. Soc. Chem. Ind.	Journal of the Society of Chemical Industry.
Medd. K. Vetenskapsakad. Nobel-Inst.	Meddelanden från Kongl-Vetenskapsakademiens Nobel-Institut.

Contracted Title.	Full Title.
Phil. Mag.	Philosophical Magazine.
Phys. Review.	Physical Review.
Proc. Phys. Soc. London.	Proceedings of the Physical Society of London.
Sci. Proc. Dubl. Soc.	Scientific Proceedings of the Royal Dublin Society.
Sitzungsber. Akad. Wiss. Wien.	Sitzungsberichte der [Mathematisch-Naturwissenschaftlichen Klasse] der Kaiserlichen Akademie der Wissenschaften, Wien.
Svensk Kem. Tidskr.	Svensk Kemisk Tidskrift.
Z. anal. Chem.	Zeitschrift für analytische Chemie.
Z. angew. Chem.	Zeitschrift für angewandte Chemie.
Z. physikal. Chem.	Zeitschrift für physikalische Chemie.
Z. Ver. deutsch. Ingen.	Zeitschrift des Vereines deutscher Ingenieure (this Society also issues the Mitteilungen über Forschungsarbeiten).

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TRANSLATOR.

PART I

1. INTRODUCTION

THE separation of liquid mixtures by repeated vaporisation is carried out industrially on a large scale, and the apparatus required for this purpose forms an important, often the most important, part of many chemical plants.

Although it is obviously necessary that those who design, construct and operate such apparatus should possess adequate knowledge of the changes that take place in it, nevertheless, so far as we know, no other treatise has hitherto been published which deals in any way exhaustively with the mechanism of these changes. The reasons for this are, probably, that the changes appear at first sight to be more complex than they really are, and that in only a very few cases do we possess the physical data that are necessary for a thorough mathematical treatment, and these data are dispersed throughout the literature. It is only quite recently that the data for a few mixtures have been determined with sufficient accuracy.

Furthermore, we do not yet possess any really practical formulæ for finding the composition of vapours evolved from boiling mixtures of known composition, and consequently we have to rely upon the few results that have been obtained by investigators in this field; it is, however, legitimate to hope that the many *lacunæ* will gradually be filled.

The problem presented by the latent heat of vapour mixtures also remained unsolved for a long time, and only after numerous attempts [1] was a solution found which appears to be satisfactory, at least for vapours which do not interact chemically. In the earlier editions of this work, the method given for determining latent heats was, fortunately, the same as that which is now held to be correct; and we shall now attempt to show how, on this foundation, the chief dimensions of apparatus working under optimum conditions can be calculated, provided that the

[1] G. Witt, *Arkiv Matem. Astron. Fysik Akad. Stockholm*, 1912, **7**, No. 32; R. C. Fenner and F. K. Richtmyer, *Phys. Review*, 1905, **20**, 77; F. Dolezalek, *Z. physikal. Chem.*, 1910, **71**, 191.

physical properties of the substances concerned are sufficiently well known.

It will be our aim to set out the principles underlying the fractional distillation of liquid mixtures, not to enter into details of construction, important as these are for the manufacturers and operators of the plant. Elsewhere it may be possible to discuss details relating to constructional materials, pressure, temperature, mixing proportions, fuels, etc.: to consider them here would, in our opinion, only dissipate interest.

In the first place, we propose to give a general explanation of the changes that occur in the apparatus: then to treat of the masses and movements of vapours and liquids, and the theoretical quantities of heat to be applied or recovered: next, to deduce the relevant mathematical expressions: and, lastly, to demonstrate how these expressions may be used to calculate the required dimensions of apparatus to be employed in separating a number of liquid mixtures.

2. ASSUMPTIONS

The following assumptions are made throughout this work:

1. The liquid mixtures considered consist only of two components, which are miscible in all proportions.
2. Liquids and vapours are always at boiling-temperature unless otherwise stated.
3. The latent heat of the vapour arising from a liquid mixture at its boiling-point is equal to the sum of the latent heats of the components of that vapour.

The third assumption (used by the author in his earlier work) appears to be confirmed by the researches of Daniel Tyrer [1] on vapours which do not interact chemically. In support of this

[1] D. Tyrer, *J. Chem. Soc.*, 1911, **99**, 1633; 1912, **101**, 81, 1104. Tyrer concludes that the latent heats of mixtures of non-reacting vapours follow Trouton's rule, $\frac{LM}{T} = \text{const.}$ In this expression, the molecular weight $M = \frac{100}{\frac{C}{M_a} + \frac{100 - C}{M_b}}$, where M_a and M_b are the mol. wts. of the components a and b; C is the percentage of a in the mixture. If L_a and L_b are the latent heats of the components at their absolute boiling-temperatures T_a and T_b: $\frac{LM}{T} = \frac{1}{2} \cdot \frac{L_a M_a}{T_a} + \frac{1}{2} \cdot \frac{L_b M_b}{T_b}$.

view, Table 1 is given (pp. 166–167). In this table, the latent heats of the vapour mixtures found experimentally by Tyrer are given under the heading T in the third and seventh columns; the values under H in the fourth and eighth columns are computed from the equation :

$$C = a \,.\, \alpha + w \,.\, \beta \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where a and w denote the weights, α and β the latent heats, of the component vapours.

It will be seen that the values for T and H agree well, notwithstanding that the latent heats of the component vapours were assumed not to fluctuate with the temperature. The latent heats at the boiling-points of the mixtures would have been used had they been known in every case; actually, the latent heats of the components at their normal boiling-points were taken. The significance of Tyrer's figures for the composition of associated vapours and liquids is brought out more clearly by the curves shown in Chart I, the abscissæ giving the percentages of low-boiling component in the liquids and the ordinates the percentages of it in the vapours.

4. The latent heat of all liquids changes with the pressure of the vapours upon them, and as this pressure is not the same in all parts of the apparatus (being, like the temperature, somewhat lower at the top than at the bottom), the latent heat changes accordingly. For the sake of simplicity, it will be assumed that these differences in pressure are without influence; in reality, their effect is very small.

5. The latent heat of vapour mixtures changes with their composition. This change will always be considered in the manner shown by equation (1); but the latent heats α and β of the components, which also change with the boiling-temperature of the mixture, are assumed to remain constant, mainly because the extent of the variation was not known in all cases, and partly because the calculations would otherwise have become too complicated. This assumption is also of little moment, particularly when the difference between the normal boiling-temperatures of the components is small. Our object is to obtain results that can be applied in the construction of plant, not to indulge in purely theoretical considerations.

6. The latent heat of vapour mixtures whose components

interact chemically is probably not the sum of the individual latent heats; but as such mixtures have not been investigated (so far as is known), to avoid inconsistency it will be assumed that Trouton's rule also applies to them.

7. The composition of the vapour mixture arising from a liquid mixture depends entirely upon the composition of the liquid: the two are always related, but the exact nature of the relationship cannot yet be expressed by a convenient formula applicable to a number of cases, although many eminent physicists have investigated the subject. In general, the vapours contain a higher percentage of low-boiling component than the liquid. The low-boiling component will be represented by L and the high-boiling component by S.

Let us imagine a certain weight D of vapour mixture to be present above a certain weight F of a boiling liquid mixture. This system may have resulted either by D being vaporised from the liquid mixture $F + D$, or by F being condensed from the vapour mixture $F + D$; in either case, the composition ratios of F and D are the same. The second mode of formation is called dephlegmation and condensation.

If we can predict the composition of the vapour above a boiling liquid mixture of known composition, we can also predict the composition of the boiling liquid situated below a known vapour mixture. If a vapour mixture be partly condensed, then the condensate must have the same composition as a liquid which would yield a vapour identical with the uncondensed portion of the original vapour mixture. Speaking generally, we are not yet able to calculate the composition of the vapour from a liquid mixture of known composition, or *vice versa*: the relationship can only be determined by careful and difficult experimentation. Communications dealing with such determinations are to be found in the literature, and some of them will be considered in these pages.

3. ALPHABETICAL SYMBOLS TO BE EMPLOYED

Weights of materials, in kilograms, will be represented by small roman letters, thus

a = Weight of acetone, alcohol (ethyl), ammonia, argon, ether, formic acid.
b = ,, ,, benzene.
e = ,, ,, acetic acid.
l = ,, ,, air.
m = ,, ,, methyl alcohol.
n = ,, ,, nitrogen.
o = ,, ,, oxygen.
w = ,, ,, water.
f = ratio $\frac{\text{high-boiling component}}{\text{low-boiling component}}$, *e.g.*, $\frac{S}{L}$, $\frac{w}{a}$, $\frac{o}{n}$, $\frac{e}{w}$, $\frac{w}{m}$.
α = latent heat of vaporisation of 1 kg. of low-boiling component.
β = latent heat of vaporisation of 1 kg. of high-boiling component.
C = latent heat of a liquid-mixture or of a gaseous mixture (the liquid is sometimes called the "wash" or the "solution").

The two parts of a mixture will be called the components, the individual substances, or the low-boiling and high-boiling components; the low-boiling component will occasionally be termed "spirit." A mixture will be designated rich, strong, high-grade, or poor, weak, low-grade, according as it contains much or little of the low-boiling component.

Suffixes attached to the letters show the section or part of the apparatus where the substances under consideration are located. Capital letters as suffixes refer to liquids and small letters to vapours; the former are replaced by the latter when a liquid is vaporised.

Symbols	*Reference*
a e m n o w f t C	The original mixture.
a_a e_a m_a n_a o_a w_a f_a C_a	Vapour in boiling-vessel or in lower part of boiling column.
a_B e_B m_B n_B o_B w_B f_B C_B	Reflux into boiling-vessel.
a_D e_D m_D n_D o_D w_D f_D C_D	Liquid on any given plate in the columns:
a_d e_d m_d n_d o_d w_d f_d C_d	vapour from this liquid.
a_e e_e m_e n_e o_e w_e f_e C_e	Vapour from reflux condenser (*i.e.*, of final product).

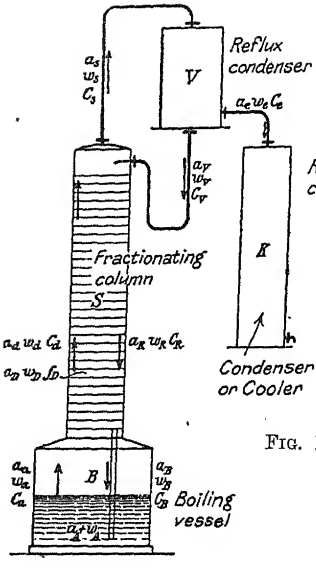


FIG. 1.

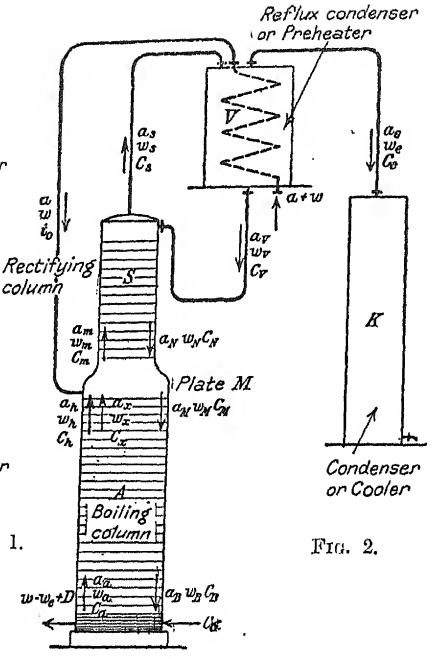


FIG. 2.

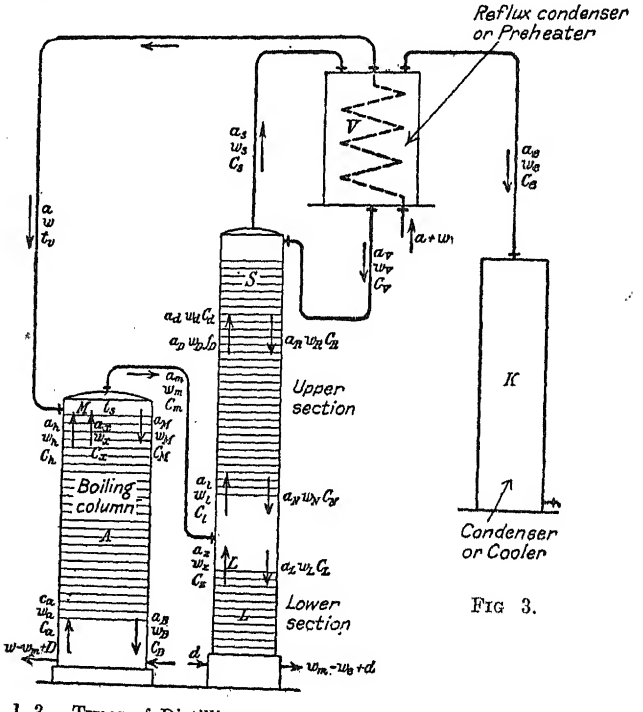


FIG 3.

FIGS. 1–3.—Types of Distilling Apparatus, indicating the Parts to which the Symbols apply.

a_E								Liquid giving rise to a_e and w_e.
							C_g	Total heat-expenditure.
a_h	e_h	m_h	n_h	o_h	w_h	f_h	C_h	Vapour for heating liquid on plate M.
a_L	e_L	m_L	n_L	o_L	w_L	f_L	C_L	Liquid on top plate of lower part (L) of rectifying column:
a_l	e_l	m_l	n_l	o_l	w_l	f_l	C_l	vapour from this liquid.
a_M	e_M	m_M	n_M	o_M	w_M	f_M	C_M	Liquid on top plate (M) of boiling-column:
a_m	e_m	m_m	n_m	o_m	w_m	f_m	C_m	vapour from this liquid.
							C_o	Secondary heat to be applied in rectifying column.
a_N	e_N	m_N	n_N	o_N	w_N	f_N	C_N	Reflux liquid from bottom plate of rectifying column.
							C_K	Heat given up by final product (liquid).
a_R	e_R	m_R	n_R	o_R	w_R	f_R	C_R	Reflux liquid from any given plate in the columns.
							C_{st}	Heat-loss of apparatus by radiation.
							C_v	Heat expended in preheating.
							C_u	Secondary heat to be applied in boiling-column.
a_s	e_s	m_s	n_s	o_s	w_s	f_s	C_s	Vapour issuing from top of rectifying column.
a_V	e_V	m_V	n_V	o_V	w_V	f_V	C_V	Liquid condensate from reflux condenser.
							t_v	Temperature of the preheated liquid.
a_x	e_x	m_x	n_x	o_x	w_x	f_x	C_x	Vapour ascending on to plate M (plus that used for heating the liquid).
a_z	e_z	m_z	n_z	o_z	w_z	f_z	C_z	Vapour ascending on to top plate of L.

To facilitate reference, the alphabetical symbols are inserted in Figs. 1, 2, and 3, which represent common types of distilling apparatus.[1]

4. EXPLANATION OF THE CHANGES OCCURRING DURING INTERMITTENT (PERIODIC) RECTIFICATION OR CONTINUOUS SEPARATION

It is proposed first to consider the phenomena that occur in rectifying apparatus of the intermittent type (Fig. 1). Such apparatus consists as a rule of a boiling-vessel, B, which is charged with the whole of the mixture to be fractionated, and in which as much liquid as necessary is vaporised: the fractionating column, S, in which the components are separated: the reflux condenser (or dephlegmator [2]), whose function is to condense some of the vapour arising from the column and to return the condensate to that column: and the condenser or cooler, K, in which the vapour of the final product is condensed and the

[1] In Figs. 2 and 3 the reflux condenser is shown acting as a preheater for the feed liquor, which serves as cooling agent. This arrangement is by no means always used, but it appears to be very popular in Germany.—(TRANSLATOR.)

[2] The word "dephlegmator" is derived from the French alcohol industry and is [illegible] it gives the idea of separation, which is not its true function.

distillate cooled. The vapours arising from the liquid mixture in the boiling-vessel are richer in low-boiling component than the liquid itself. These vapours rise in the column, condense in the liquid on each plate, and in so doing liberate vapours that are still richer in the more volatile component. Assuming that no heat is lost, the rising mass of vapour will give up the same amount of heat to the boiling liquid on each plate, so that the new vapours produced on each plate, although of different composition, always contain the same quantity of heat. The heat-contents of all the vapours produced on the plates are therefore equal to one another. Further, the liquids which descend from the plates (reflux liquids) will all possess the same latent heat, *i.e.*, the heat withdrawn from the vapour in the reflux condenser; and this amount of heat is less than that applied in the boiling-vessel by the quantity that is retained by the final product :—

$$C_a = C_d = C_s = C_V + C_e = C_R + C_e = C_B + C_e \quad . \quad . \quad (2)$$

The vapour rising from the top plate of the column ($C_s = C_d = C_a$) and entering the reflux condenser contains but little of the high-boiling component. Some of this vapour passes on to the cooler (condenser) to appear as final product (C_e), whilst the rest, usually the greater part (C_V), is condensed and flows back as a liquid rich in low-boiling component on to the top plate of the column, from which it descends further.

On every plate the reflux gives up some of its low-boiling component to the rising vapours, and takes in exchange an equivalent amount of high-boiling component.

Finally, the liquid from the lowest plate in the column flows into the boiling-vessel having a composition not very different from that of the mixture in that vessel. The composition of each of these liquids changes during the distillation. If all the vapour ascending from the column is condensed in the reflux condenser, it returns as liquid to the boiling-vessel, so that the composition of this reflux might conceivably be the same as that of the vapour rising directly from the boiling-vessel, but it can never be richer in low-boiling component.

On the other hand, the reflux into the boiling-vessel can never be weaker than the liquid in that vessel, because the ascending vapours would at once enrich a liquid weaker than that out of which they arose.

The composition of the reflux into the boiling-vessel can, therefore, vary between the following limits: its percentage

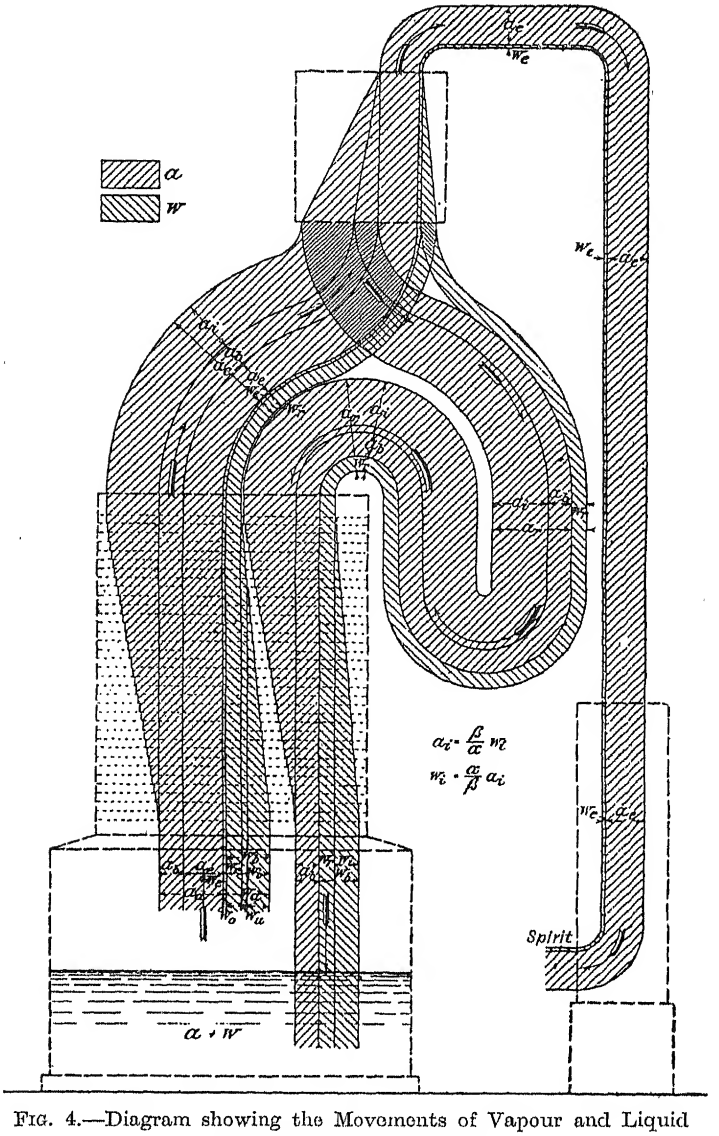


FIG. 4.—Diagram showing the Movements of Vapour and Liquid in a Rectifying Apparatus.

content of low-boiling component may in the most favourable circumstances be nearly equal to that of the vapour coming

from the boiling-vessel, but it can never be less than that of the liquid in that vessel.

That part of the vapour which emerges from the column, and which does not pass into the condenser (cooler), must be condensed in the reflux condenser and returned to the column and boiling-vessel; and the smaller the weight of this reflux, the lower is the heat-consumption of the apparatus. Therefore, for a given yield of final product, those forms of apparatus require the least expenditure of heat in which the amount of reflux is a minimum; and, it may be at once stated, that this occurs when, *ceteris paribus*, the number of plates in the column is a maximum.

In Fig. 4 [1] an attempt is made to represent graphically the phenomena taking place in the apparatus; the rising vapour and the descending liquid are shown in dissected form in order to bring out their mutual relations.

From the liquid $a + w$ in the boiling-vessel whose composition ratio is given by $\frac{w}{a} = f$, there ascends a vapour $a_d + w_d$ whose ratio $\frac{w_d}{a_d} = f_d$ is determined by the ratio f.

We can, however, imagine the total vapour mixture $a_d + w_d$ to be made up of several parts. First, it must contain the amount $a_e + w_e$, which ultimately reaches the condenser as final product; but, secondly, it must also contain a certain amount of w, so that its ratio to a_e becomes equal to f_d. Let this additional amount of w be called w_o; then

$$\frac{w_e + w_o}{a_e} = f_d \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Therefore,

$$w_o = a_e f_d - w_e \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

i.e., the vapour $a_e + w_e + w_o$ ascends from the boiling-vessel, but only the weight $a_e + w_e$ finally leaves the apparatus, so that w_o flows back into the vessel. We know, however, that the reflux into the boiling-vessel does not consist only of w; it must contain *at least* as much a as the original charge (f) in the boiling-vessel, and *at most* as much as is present in the ascending vapour (f_d).

A certain weight of a, viz., a_b, must, therefore, rise with $a_d + w_d$ in order that it may return with w_o to the boiling-vessel.

[1] The alphabetical symbols in Fig. 4 differ slightly from those given in Figs. 1–3, and are used only in equations numbered (3) to (21).

But a_b cannot ascend alone; it must be accompanied by an amount of w that will satisfy the relation f_d. Hence

$$\frac{w_u}{a_b} = f_d \text{ and } \frac{w_o + w_u}{a_b} = f_b \quad . \quad . \quad . \quad . \quad (5)$$

Subtracting, we obtain

$$\frac{w_o}{a_b} = f_b - f_d \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

$$a_b = \frac{w_o}{f_b - f_d} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

Putting $w_o + w_u = w_b$, we obtain from equations (5) and (7)

$$w_b = a_b f_b \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

$$C_b = a_b \,.\, \alpha + w_b \,.\, \beta \quad . \quad . \quad . \quad . \quad (9)$$

$$a_d = a_e + a_b \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

$$w_d = w_e + w_b \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

$$C_d = a_d \,.\, \alpha + w_d \,.\, \beta \quad . \quad . \quad . \quad . \quad . \quad (12)$$

The values of the other quantities are derived as follows:

Assuming that the column loses no heat by radiation, the heat-content of the rising vapours remains constant from bottom to top, for no heat enters or leaves them, *i.e.*,

$$C_d = C_s = a_s \,.\, \alpha + w_s \,.\, \beta \quad . \quad . \quad . \quad . \quad (13)$$

From the reflux condenser a portion of the vapour enters the cooler and constitutes the final product $a_e + w_e$, whose heat-content is given by

$$C_e = a_e \,.\, \alpha + w_e \,.\, \beta \quad . \quad . \quad . \quad . \quad . \quad (14)$$

The larger portion of the vapour which enters the reflux condenser is there deprived of its latent heat on being condensed and converted into reflux. This loss of heat is represented by

$$C_R = a_r \,.\, \alpha + w_r \,.\, \beta \quad . \quad . \quad . \quad . \quad . \quad (15)$$

As the reflux flows down the column on its way back to the boiling-vessel, it has no opportunity either of gaining or losing heat; and although this reflux changes considerably in composition, by giving up low-boiling component to the ascending vapour and receiving in exchange high-boiling component in the ratio $\alpha : \beta$, the quantity of heat required to vaporise it remains the same from start to finish. Therefore

$$C_R = C_B = a_r \,.\, \alpha + w_r \,.\, \beta \quad . \quad . \quad . \quad . \quad (16)$$

If the reflux $a_r + w_r$ is at boiling-temperature then its ratio $\frac{w_r}{a_r} = f_r$ must bear a definite relation to the ratio $\frac{w_e}{a_e} = f_e$ of the vapour $a_e + w_e$ above it. Since f_e is known, f_r is also known. The aid of tables containing experimental data must be sought at this stage. The values of a_r and w_r are found from

$$\frac{w_r}{a_r} = f_r. \quad C_B = a_r \,.\, \alpha + w_r \,.\, \beta \quad . \quad . \quad . \quad (17)$$

$$a_r = \frac{C_B}{\alpha + f_r \,.\, \beta} \text{ or } \frac{C_R}{\alpha + f_r \,.\, \beta} \quad . \quad . \quad . \quad (18)$$

$$w_r = f_r a_r$$

Finally,

$$a_s = a_e + a_r \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (19)$$

$$w_s = w_e + w_r$$

$$C_s = C_a = C_B + C_e = C_R + C_e \quad . \quad . \quad . \quad (20)$$

With the aid of these twenty equations, which to some extent can be derived from one another, it is possible to calculate all the values required, provided that in addition to the physical properties of the substances to be separated we also know:

(1) The composition of the initial charge: $\frac{w}{a}$.

(2) The output of the apparatus in a given time: $a_e + w_e$.

(3) The composition of the reflux into the boiling-vessel f_R; *or*

(3*a*) The heat C_V withdrawn from the vapours in the reflux condenser.

We know already that the composition of the reflux into the boiling-vessel can vary between f and f_a without affecting the distillation; and also that the heat-consumption of the apparatus depends very largely on this composition.

According to equation (20), the total heat-consumption of an apparatus of given performance is

$$C_a = C_B + C_e$$

and since C_e $(= a_e\alpha + w_e\beta)$ is constant for a given performance, C_a can become smaller only if C_B becomes smaller.

Since $\quad C_B = a_R\alpha + w_R\beta = a_B\alpha + w_B\beta$

and $\quad w_B = a_B f_B$

Therefore $\quad C_B = a_B(\alpha + f_B\beta)$.

C_d, therefore, becomes smaller as the weight of a_d and the ratio $\frac{w_B}{a_B}$ become less.

For a definite output, the heat required in a rectifying apparatus diminishes as the composition of the reflux into the boiling vessel $\left(\frac{w_B}{a_B} = f_B\right)$ *approaches that of the contents of the boiling vessel* $\left(\frac{w}{a}\right)$.

This ideal cannot be attained in practice, because, as we shall see more clearly later on, extremely high columns would have to be used—a point of considerable importance in the construction of such apparatus.

Referring again to Fig. 4, we observe that from the boiling-vessel there ascend:

(1) the vapour $a_e + w_e$, which traverses the column, the reflux condenser and the condenser (cooler) before it leaves the apparatus;

(2) the vapour w_r, which traverses the column from bottom to top, is condensed in the reflux condenser, and then, together with a_r, passes back through the column as reflux;

(3) the vapour w_i, which is condensed on its way through the column, but sets free an equivalent weight of a_i. The latter is condensed in the reflux condenser, but is again vaporised by the ascending vapour w_i as it passes down the column;

(4) the vapour a_b, which passes through the column, is condensed in the reflux condenser, and together with $w_b (= w_r + w_i)$ returns to the boiling-vessel.

5. CHANGES ON THE COLUMN PLATES

As already indicated, the vapours ascending from the plates in a column consist of:

(1) the vapours $a_e + w_e$, which remain unchanged on all the plates from bottom to top, and finally leave the apparatus as end-product;

(2) the vapours which, together with those in (1) and those which condense in the reflux condenser, form the reflux $a_V + w_V$. These vapours alter in composition from plate to plate. On every plate they give up to the reflux some

high-boiling component, which descends from the plate, and take up some low-boiling component from the reflux which descends on to this plate from above; therefore their latent heat remains unchanged: $C_B = C_R = C_V$.

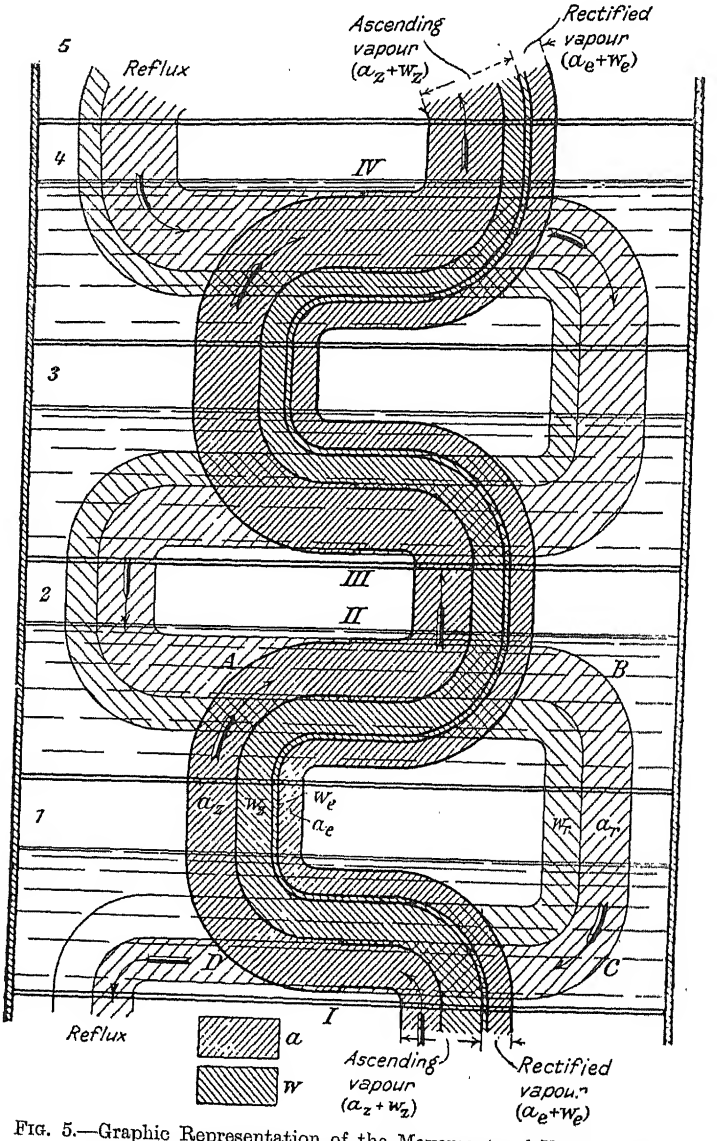


FIG. 5.—Graphic Representation of the Movements of Vapour and Liquid in the Column of a Rectifying Apparatus.

This process is illustrated in Fig. 5, which shows how at I, II, III, IV, the ascending vapour a_z increases and w_z decreases, and how the reflux loses as much a_r as it gains w_r.

The changes can also be pictured as follows :

On every plate the fraction $a_e + w_e$ of the ascending vapours is completely condensed and returns from this plate as reflux to the plate below. The vapour $a_e + w_e$ remains unaltered.

The heat which is set free by the condensation taking place on each plate exactly suffices to vaporise all the reflux which descends on to it from above. The new mixture of vapours thus produced rises, together with $a_e + w_e$, to the plate immediately above, where it is again completely condensed, gives rise to a new mixture of vapours, and allows the reflux it has taken up on this higher plate again to fall back on the plate below.

In flowing from one plate to the next immediately below it, the reflux is completely vaporised and ascends as vapour, together with $a_e + w_e$, to the next higher plate, where it is condensed and again falls back as reflux.

This cycle can be followed in the diagram (Fig. 5) along the curved lines A, B, C, D. It will be seen that the unchanging current of rectified vapour $a_e + w_e$ is accompanied from plate to plate by a vapour $a_z + w_z$ which, on condensing in the liquid of the next plate, gives rise to a new vapour, but itself returns to the plate immediately below in order to resume its *rôle* of accompanying vapour. Every such vapour completes a cycle in the space between two plates without changing in composition; but the new accompanying vapours set free on the plates have a different composition, becoming richer in low-boiling component as they ascend.

The amount and composition of the reflux flowing on to a plate are exactly the same as the amount and composition of the vapour which rises from the plate to accompany the rectified vapour $a_e + w_e$. The greater the weight of reflux flowing on to a plate in relation to the weight of the rectified vapour, the smaller is the difference in composition between the total vapour rising from this plate and the reflux.

Since, however, the composition of the total vapour ($a_e + w_e + a_z + w_z$) ascending from a plate bears the oft-mentioned definite relation to the composition of the reflux, it follows directly that *the difference in composition of the reflux liquids on*

two successive plates increases as their total amount increases in relation to the quantity of final product; in other words, the increase in percentage content of low-boiling component grows from plate to plate pari passu *with the ratio of the weight of reflux to the weight of vapour of final product.*

For a given amount of final product, the greater the amount of reflux formed the smaller is the number of plates needed in the column; but this arrangement involves a greater consumption of heat because the reflux has to leave the boiling-vessel in the form of vapour.

The above considerations teach us, therefore, what was indicated previously, viz., that columns are more efficient the more plates they contain, because less reflux has to be vaporised; and also that low columns can give good results, although these require a greater heat-expenditure because they need a larger amount of reflux.

Other things being equal, the consumption of steam in the columns is roughly proportional to the weight of the reflux.

Now that all the changes taking place in the boiling-vessel and in the column have been explained, it is easy to see that the following equation is applicable to the vapour in the boiling-vessel (Fig. 4):

$$\frac{w_e + w_b}{a_e + a_b} = f_d \quad . \quad . \quad . \quad . \quad . \quad . \quad (21)$$

or, according to Fig. 1,

$$\frac{w_e + w_B}{a_e + a_B} = f_a \quad . \quad . \quad . \quad . \quad . \quad . \quad (21a)$$

It is also obvious that if $a_R + w_R$, f_R, C_R represent, generally, the weight, composition ratio, and latent heat of the reflux from any plate in a column, and if a_d, w_d, f_d represent the weights of the components and the ratio of the vapour which ascends on to this plate, the following equation is applicable to any arbitrary, horizontal section between two plates:

$$\frac{w_e + w_R}{a_e + a_R} = f_d \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (22)$$

and the following for a section between the top plate and the reflux condenser

$$\frac{w_e + w_V}{a_e + a_V} = f_c \quad . \quad . \quad . \quad . \quad . \quad . \quad (22a)$$

Transposing in equation (22), we obtain

$$w_e + w_R = a_e f_d + a_R f_d$$
$$a_e f_e + a_R f_R = a_e f_d + a_R f_d$$
$$a_R(f_R - f_d) = a_e(f_d - f_e)$$
$$a_R = \frac{a_e(f_d - f_e)}{f_R - f_d} \quad . \quad . \quad . \quad . \quad . \quad (23)$$

Now, because

$$a_R\alpha + w_R\beta = C_R = a_R(\alpha + f_R\beta)$$

and

$$a_R = \frac{C_R}{\alpha + f_R\beta}$$

Therefore

$$C_R = \frac{a_e(f_d - f_e)\ (\alpha + f_R\beta)}{(f_R - f_d)} \quad . \quad . \quad (24)^1$$

This simple equation gives all the information needed concerning the conditions in the column. It shows how to find the amount of heat that must be withdrawn from the reflux (C_V) in the reflux condenser in order to produce from a vapour mixture of ratio f_d a definite weight of low-boiling component a_e of definite composition ratio (purity) f_e, if the reflux is to have the ratio f_R; or it gives the values for f_d and f_R if the latent heat of the reflux C_R is to be used in producing the final product $a_e + w_e$.

We have already learnt that the heat-expenditure (calculated on unit weight of product of predetermined composition) for a mixture of given composition is lowest when the composition ratio of the reflux f_R is equal to that of the liquid from which the vapour f_a is evolved. This also follows from equation (24), for if f_R increases, the numerator of the fraction also increases, but the denominator increases still more. The rectifying columns must accordingly be arranged so that this result may be approached, *i.e.*, that the percentage of low-boiling component in the reflux which returns to the boiling-vessel is as nearly as possible equal to its percentage in the original liquid mixture.

[1] The equation for the space between reflux condenser and column is:

$$C_V = \frac{a_e(f_s - f_e)\ (\alpha + f_V\beta)}{f_V - f_c} \quad . \quad . \quad . \quad . \quad . \quad (25)$$

and that for the space between column and boiling vessel:

$$C_B = \frac{a_e(f_a - f_e)(\alpha + f_B\beta)}{f_B - f_a} \quad . \quad . \quad . \quad . \quad . \quad (26)$$

where $C_V = C_R = C_B$.

It will be seen later that this end can only be completely achieved by using a very large number of plates, so that practical considerations enforce a compromise; for it is obvious that with a decreasing amount of reflux, progressive rectification of the vapour, in respect of its content of low-boiling component, must also decrease from plate to plate.

Equation (24) also shows the smallest possible percentage of low-boiling component in the vapour f_a (and also, of course, in the original liquid), from which a certain weight of a_e can be obtained by means of a definite amount of reflux-heat.

Further, equation (24) or (25) or (26) can be used to calculate the ratio $\frac{w_e}{a_e} = f_e$, *i.e.*, the highest attainable percentage yield of final product $a_e + w_e$ from the mixture $a_R + w_R$ (with ratio f_R) when the heat-expenditure is $C_R + C_e$ (or $C_B + C_e$ or $C_V + C_e$); and, finally, to calculate the weight of product $a_e + w_e$, when all the quantities f_B, f_a, f_s, f_e, C_B, C_R, and C_V are known.

The weaker the original liquid is in low-boiling component, the greater will be the amount of heat needed to obtain a given weight of high-grade product $(a_e + w_e)$. This statement does not, however, apply to all liquid mixtures and all mixing proportions. That the amount of heat needed for the reflux increases continuously as the original liquid gets poorer and poorer, depends upon the fact that the difference in composition between liquid and associated vapour remains approximately constant; but in many, perhaps in most cases, this difference varies within wide limits, as with ethyl alcohol, methyl alcohol, and acetone. With weak mixtures this difference may become large, with mixtures of medium strength small, and with rich mixtures again large. This will be clearly shown later, when specific mixtures are considered. Attention must be paid to this matter in the construction of plant, as well as in works practice. It may be taken as generally true that in the periodic separation of liquid mixtures, the heat-requirement rises as the liquid in the boiling-vessel gets poorer in low-boiling constituent, and reaches a maximum towards the end of the distillation. Since the low-boiling component is continuously removed (in a more or less pure state as final product) from the mixture in the boiling-vessel, this mixture and its associated vapour must become weaker and weaker; consequently the amount of heat to be expended, C_a, to produce the same weight of product must increase.

The assumption underlying the foregoing interpretation is that the vapour ascending into the liquid on a plate is completely condensed in it. This condensation is possible because the liquid is always a little cooler than the vapour, and becomes certain if the interface between vapour and liquid is sufficiently large. The interface is formed by the bubbles of vapour in the liquid, by the resulting froth and by the drops and small bubbles expelled from it. There is no doubt that the whirling, bubbling, foaming layer of liquid and vapour, which forms on the surface of the boiling liquid, provides a very large area of contact between them; and this is only obtained if the vapour enters the liquid in a properly divided state and with a considerable velocity, although the latter must not be too great, otherwise the vapour will carry liquid with it from plate to plate. On every plate the incoming vapour should be completely condensed and an entirely new vapour should be formed.

It might be considered desirable to increase the action of the rectifying columns by introducing filling material, such as spheres, prisms, or tetrahedra made of wire, so that condensation of vapour and vaporisation of liquid can take place throughout the whole column; but it is difficult, if not impossible, artificially to provide surfaces so efficient as bubbles, drops, and mist, and even more difficult to ensure that their large surfaces are always covered with liquid.

Even the use of such filling material for diminishing the resistance in the column is unlikely to be successful, for the inserted objects would reduce the cross-section of the column, cause frequent changes in direction and much friction, so that the actual resistance would be increased rather than diminished. The vapour pressure in an ordinary column is approximately equal to that of the sum of the liquid layers to be traversed, *i.e.*, it is not necessarily large; and the advantages of a somewhat smaller pressure have never been demonstrated.

The use of film columns can only be justified in exceptional cases, and there is no justification for the proposal to use special artificial means for preventing possible separation of gases and vapours. Stratification of gases and vapours into layers, according to their density, has never been observed, and, moreover, would be in opposition to known laws. That well-constructed columns of the bell-and-tray type act in the manner described above is shown by the fact that their performances agree with

previous calculation, provided that the physical properties of the substances to be separated have been duly considered. Their behaviour approaches theoretical perfection as nearly as any mechanical contrivance can: a statement that cannot be made of film columns.

At starting up, every apparatus contains air, which is quickly expelled as soon as vapour at boiling-temperature is produced in sufficient amount: for saturated vapour at atmospheric pressure does not permit the simultaneous presence of air. The very small amount of air, derived from the original charge in the boiling-vessel, that might possibly find its way into the apparatus during the course of operations is so minute in comparison with the amount of vapour present, and the two are so intimately mixed, that it may be safely neglected. Pockets of air on the plates that might conceivably hinder rectification, and have to be removed by special contrivances, do not occur.

The currents of air that are often observed to flow in and out of the air-tubes of the condenser (cooler), are not due to undetected accumulations of air in the columns, but to occasional irregularity in the supply of vapour and water to the condenser, which makes the condensation intermittent. The observed air-currents are caused by fluctuations in the volume of the air-space in the condenser.

6. THE REFLUX CONDENSER

The function of the reflux condenser is to liquefy a considerable portion of the vapour that enters it from the fractionating column, and to return it to the column as reflux; the rest of the vapour passes on to the condenser (cooler), from which it is run off as final product. If both the condensate and the residual vapour in the reflux condenser retained the same composition as the vapour from which they were formed, the column would still work efficiently, because the reflux would contain the maximum amount of low-boiling component, and when it descended on to the top plate of the column it would again give rise to a vapour of maximum richness. This is what often happens, or nearly happens, in practice; for if the column has done its work so well that it has effected as complete a rectification as possible—the liquid and vapour on the top plate having approximately the same composition—then there is no further work of this kind

for the reflux condenser to do. Actually, a very small amount of separation takes place in the reflux condenser, but it may be so small as to be undetectable. If, however, separation in the rectifying column has been imperfect, so that the vapour entering the reflux condenser still contains much high-boiling component, the reflux condenser will effect a very appreciable concentration; this is observed daily on many stills of the continuous type.

Unfortunately, exact investigations on the composition of the condensate in reflux condensers have not been published, and the many observations of the author on this point do not permit of a definite conclusion.

The phenomena occurring in a reflux-condenser can be visualised in two ways.

I. The composition of both vapour and condensate at any point of mutual contact in a reflux condenser may be identical with that theoretically deducible from the assumption that the vapour has been formed from the condensate. In this case, the composition of the reflux from a reflux condenser, in which the vapour circulates upwards and the condensate downwards, is determined by the circumstance that this reflux was the source of the *vapour entering the reflux condenser;* but the composition of the reflux from a reflux condenser in which both vapour and condensate travel downwards must be in accordance with the assumption that the reflux was the source of the *vapour of the final product.* These alternatives are expressed mathematically as follows:

$$\frac{w_s - w_{V_1}}{a_s - a_{V_1}} = f_e \quad \text{or} \quad \frac{w_e + w_V}{a_e + a_V} = f_s \quad . \quad . \qquad (27)$$

$$a_s f_s - a_{V_1} f_{V_1} = a_s f_e - a_{V_1} f_e \qquad a_e f_e + a_V f_V = a_e f_s + a_V f_s \qquad (28)$$

$$a_{V_1} = \frac{a_s(f_s - f_e)}{f_{V_1} - f_e} \qquad a_V = \frac{a_e(f_s - f_e)}{f_V - f_s} \quad . \quad . \qquad (29)$$

$$C_{V_1} = \frac{a_s(f_s - f_e)(\alpha + f_{V_1}\beta)}{f_{V_1} - f_e} \qquad C_V = \frac{a_e(f_s - f_e)(\alpha + f_V\beta)}{f_V - f_s} \qquad (30)$$

In these equations, for ascending vapour, f_{V_1} represents the composition ratio of the liquid on the top plate which produces vapour of ratio f_s; for descending vapour, f_V is the ratio of the liquid which yields the vapour of the final product of ratio f_e.

Example (*v.* Table 2).—It is required to produce in a reflux condenser 1 kg. of ethyl alcohol of 85·7% wt. (90° vol.)($f_e = 0{\cdot}1669$) from 82% vapour in the column ($f_s = 0{\cdot}2195$). With rising vapour in the reflux

condenser, the strength of the reflux is 71% by weight ($f_{V_1} = 0{\cdot}4085$), and with descending vapour 80·5% by weight ($f_V = 0{\cdot}2422$).

For the first case:

$$a_{V_1} = \frac{a_s(0{\cdot}2195 - 0{\cdot}1669)}{0{\cdot}4085 - 0{\cdot}1669} = (a_{V_1} + a_e) \,.\, 0{\cdot}2177 = (a_{V_1} + 1)0{\cdot}2177.$$

$$a_{V_1} = 0{\cdot}278 \text{ kg.} \quad C_{V_1} = 0{\cdot}278(205 + 0{\cdot}4085 \,.\, 544) = 118{\cdot}70 \text{ Cal.}$$

$$a_{V_1} + w_{V_1} = 0{\cdot}3915.$$

For the second case:

$$a_V = \frac{a_e(0{\cdot}2195 - 0{\cdot}1669)}{0{\cdot}2422 - 0{\cdot}2195} = 2{\cdot}317 \text{ kg.} \quad C_V = 2{\cdot}317(205 + 0{\cdot}2422 \,.\, 544) = 780{\cdot}1 \text{ Cal.}$$

$$a_V + w_V = 2{\cdot}317(1 + 0{\cdot}2422) = 2{\cdot}878 \text{ kg.}$$

It follows, therefore, from this calculation that in the production of a given weight of final product, $a_e + w_e$, from its vapour mixture f_s, much more condensate is formed in the reflux condenser when the vapour flows downwards than when it flows upwards.

II. The second interpretation of the phenomena taking place in a reflux condenser appears, from the author's observations, to be nearer the truth. According to it, the composition of the condensate on any given part of the cooling surface is equally independent of the composition of the residual vapour and of the composition of the condensate formed above and below this part. This view assumes that the vapour and its associated condensate are related to one another as described in Section 4, and that each fraction of the condensate is removed at once from the other fractions. In favour of this view is the observation that in a reflux condenser the cooling surface is always covered with condensate; the vapour is never in contact with the metal wall, but always with the liquid. Now, since the vapour is gradually condensed *on and by* the reflux, the latter must be cooler than the former, and therefore can scarcely behave towards it otherwise than as a dry, cold wall. From this it would follow that the vapour gives up heat to the reflux (condensate), and that no new vapour is evolved.

In this case, with vapour flowing upwards through the reflux condenser, f_V in equation (29) would have a mean value between f_s and f_e

$$a_V = \frac{a_e(f_s - f_e)}{f_{V_{\text{mean}}} - f_s} \qquad C_V = \frac{a_e(f_s - f_e)(\alpha + f_{V_{\text{mean}}}\beta)}{f_{V_{\text{mean}}} - f_s} \quad . \quad (31)$$

The calculation of the mean value $f_{V_{\text{mean}}}$ will be considered in a later section: it cannot be the arithmetic mean, and has to be

calculated step by step. Using the data of the last example, the calculations for the reflux are as follows:

$$a_V = \frac{a_e(0{\cdot}2195 - 0{\cdot}1669)}{(0{\cdot}3253 - 0{\cdot}2195)} = 0{\cdot}50 \text{ kg.}$$
$$w_V = 0{\cdot}5 \,.\, 0{\cdot}3253 = 0{\cdot}1627 \text{ kg.}$$
$$C_V = 0{\cdot}5 \,.\, 205 + 0{\cdot}1627 \,.\, 544 = 191 \text{ kg. Cal.}$$

The mechanism of the condensation is probably not quite the same as that described above, because there is a number of factors concerned which are not yet properly understood; but observations made in works practice render it probable that the direction of flow of the vapour is not without influence on the results obtained.

For a column of given dimensions and output, a definite amount of reflux is required, *i.e.*, a definite quantity of heat C_V must be taken from the vapour in the reflux condenser. As the amount of heat that can be abstracted through a square metre of cooling-surface is roughly proportional to the mean difference in temperature of the vapour and the cooling-agent, it follows that by altering the amount and temperature of the cooling-agent, the amount of reflux produced can also be altered. Although water is usually employed for cooling, other liquids of higher boiling-point, air or vapour of given temperature and pressure are sometimes employed.

Water is occasionally replaced by other cooling-agents because it is thought that the vapours passing through the reflux condenser ought to be maintained at a constant and definite temperature, *e.g.*, the boiling-point of the low-boiling component, in order that all the high-boiling component may be condensed and only the low-boiling component travel on to leave the apparatus as final product. If this view were correct, it would be possible to separate, for example, alcohol and water by passing the mixed vapours through a space maintained at 78° C., or acetic acid from water by passing through a space at 100° C. Such a method is, however, useless, because saturated vapours and vapour mixtures, under constant pressure, are not cooled by abstracting heat from them; they are simply condensed, partially or entirely. The liquid produced in this way always contains fractions of *all* the components; and further, a vapour

mixture is not easily affected throughout its entire mass, but chiefly at its points of contact with the colder walls.[1]

The temperature of the condensate in the reflux condenser should not fall below boiling-temperature; but if this does happen and the cooled condensate reaches the mixture boiling on the top plate of the column, it will at once be heated up to boiling-point by some of the vapour coming from below and condensing in it, and will be enriched exactly to the same extent as if this fraction of the vapour had been condensed in the reflux condenser and had flowed back from it into the column. Such undercooling has no effect, and should be avoided, as it may give rise to other troubles.

The boiling-temperature of the reflux from the reflux condenser is always lower where it enters the column than where it flows back into the boiling-vessel; the difference in temperature may amount to 1–2° C., and in the case of certain mixtures to 10–40° C. As the reflux descends from plate to plate, changing in composition, weight, and specific heat, it must be heated up to the boiling-temperature on each plate, and every time this happens a different, though small, amount of heat is required. The sum of these heat-quantities C_o is given by the equation

$$C_o = \frac{C_R}{(\alpha\beta)_m} \cdot \sigma_m(t_B - t_V),$$

where $(\alpha\beta)_m$ is the mean latent heat, σ_m the mean specific heat, t_B the upper and t_V the lower temperature of the reflux.

The heat-quantity C_o is a fraction of the heat-quantity C_a, and since it is gradually consumed as it rises through the column, it cannot exert its full concentrating action right up to the top. This fraction is not large (0·5–5 % of C_a), and as an exact mathematical treatment of the consumption on each plate would lead to excessive complication, we shall assume that the concentrating action of this heat can be expressed by $\frac{C_o}{2}$ or $\frac{C_u}{2}$. In practice, one or other of these values must be added to C_R, according as an upper rectifying or a lower boiling-column is concerned.

For the present we may ignore the secondary heating of the reflux, but we shall consider it in the examples to be given later, and in developing the equations for continuous distillation.

[1] For footnote, see next page.

[1] F. D. Brown (*J. Chem. Soc.*, 1880, **37**, 49) experimented with small laboratory rectifying apparatus made of glass, and concluded rightly that two liquids (carbon bisulphide and benzene) can be better separated with air-cooled column-heads provided with perforated plates than with empty glass tubes, either upright or inclined. He concluded also that with glass worm-condensers, cooled to a constant temperature by the evaporation of a surrounding liquid, the distillate consists of a mixture of the two components which boils at that temperature.

Rosanoff, Lamb, and Breithaupt (*J. Amer. Chem. Soc.*, 1909, **31**, 448), in their distillation experiments with carbon tetrachloride and toluene, used a small boiling-vessel provided with a column consisting of a double-walled tube open at both ends and measuring 25 mm. long, 5 mm. internal, and 6 mm. external diameter. The tube was placed in a vessel containing cooling-water, which was stirred vigorously and maintained at a constant temperature. The vapour traversed the annular space between the tubes in an upward direction. The composition of the original charge changed from CCl_4 72·5%, $C_6H_5.CH_3$ 27·5% to CCl_4 56·21%, $C_6H_5CH_3$ 43·75%, whilst when the cooling-water was kept constant at 79° C. the composition of the distillate did not alter (CCl_4 93%); at 80·4° C. an initial charge containing 70–61·67% CCl_4 gave a constant distillate with 92·27% CCl_4.

J. F. W. Schulze (*J. Amer. Chem. Soc.*, 1914, **36**, 498), also Rosanoff, Schulze, and Dunphy (*ibid.*, p. 2480), using similar means, attempted to separate three substances. M. A. Rosanoff and co-workers (*ibid.*, 1915, **37**, 301, 1072) investigated the separation of carbon tetrachloride, toluene, and ethylene dibromide with a 400 c.c. vessel and a condenser like that described above but of different dimensions (760, 250, 270 mm.). They used five different constant temperatures, 83°, 91°, 99°, 107°, and 115° C., renewed the charge two or three times during each distillation, and collected the distillate in fractions of 15–20 c.c. They found, similarly to Brown, that definite temperatures of the cooling-agent ensure constancy of boiling-temperature of the distillates. The agreement was not quite perfect, as the last series of observations, conducted with a cooling temperature of 115°, shows :—

Charge :	CCl_4	8·2%;	$C_6H_5CH_3$	9·2%;	$C_2H_4Br_2$	82·6%.
Distillates :	,,	30·0%	,,	12·9%	,,	57·1%
	,,	29·5%	,,	13·7%	,,	56·8%
	,,	29·1%	,,	14·3%	,,	56·6%
	,,	28·4%	,,	15·3%	,,	56·3%
	,,	27·7%	,,	16·4%	,,	55·9%
	,,	26·4%	,,	18·3%	,,	55·3%

S. Young, in his book, "Fractional Distillation" (1903), discusses, *inter alia*, and to some extent illustrates by comparative tests, the gradual perfecting of laboratory rectifying apparatus constructed of glass, the devising and constructing of which are rendered difficult by the necessity for economy in space (particularly vertical space), small capacity, exactness of regulation, and easy and perfect discharge, but are facilitated by the absence of any need for economising heat. Although no small laboratory apparatus effects such rapid and perfect separation as the large apparatus used in industry (because cooling is not confined to the top, the number of plates is restricted, and the flow of reflux is not quite regular), nevertheless the improvements that have been gradually introduced point conclusively to the correctness of the views advanced in the present work, although these may not yet be known to or, if known, not yet all be admitted by the author of "Fractional Distillation." Like F. D. Brown, he also appears to believe that it is possible to effect perfect separation by maintaining the cooling-water in the condenser at the boiling

temperature of the low-boiling component; in which connection it is difficult to see how, for example, in the separation of benzene, toluene, and xylene, the cooling-water which circulates in the *open* jacket of the condenser can be maintained at 80°, 110°, or 140° C. (p. 199).

As the result of a large number and variety of observations, we are unable to agree with the views set out above. In separating mixtures, the absolute temperature of the cooling-agent in the condenser plays an almost negligible part, provided that it is below the boiling-point of the vapour in transit, and the less so because under ordinary circumstances it is by no means constant, being always lower at the bottom than at the top. Experiments in which the cooling-agent was led in at the top and led out at the bottom of the jacket were unsuccessful in every case. The form of condenser mostly used by the observers mentioned—one without a column situated below it—must have entailed a gradually increasing condensation of a considerable [illegible] our passing through it. The amount of condensate [illegible] have been irregular, although they have recorded no observations on this crucial point. In the small still-heads used, the continued partial condensation of the ascending vapour causes the uncondensed portion to become richer in low-boiling component and keeps it at a constant composition, even with a small change in the amount of heat withdrawn; but after the charge has lost the greater part of its low-boiling component, and consequently the vapour from it has become much weaker, considerably more heat must be withdrawn from the vapour in order to obtain a final distillate of approximately constant composition. If their experiments had been carried out to a finish, the observers would have found this out, but apparently they did not do so. The extent to which the amount of heat required to be withdrawn (*i.e.* the reflux-heat C_R) increases with the difference in composition of the vapour from the boiling-vessel and the vapour of the final product will be shown in subsequent equations; and gradual condensation will be treated in Sections 18B and 22F.

The temperature of the cooling-liquid in the reflux condenser may vary within wide limits, provided that the cooling-surface (multiplied by the resulting difference in temperature) withdraws from the vapour sufficient reflux-heat C_R to produce the distillate required. The absolute temperature of the cooling-agent hardly comes into consideration. Columns without superimposed reflux condensers, in which the [illegible] effected solely by their walls, suffer from various [illegible] will be discussed in Section 7, 22E; they cannot be used for exact separations.

7. IS IT BETTER TO USE A NUMBER OF REFLUX CONDENSERS, VIZ. ONE BETWEEN EVERY TWO PLATES, OR ONLY ONE, SUPERIMPOSED ON THE RECTIFYING COLUMN?

Let us consider first the case of a single superimposed reflux condenser (Fig. 1). A vapour-mixture $a_a + w_a$, of given weight and composition, ascends from the boiling-vessel, and a portion of it $a_B + w_B$, also of known weight and composition, returns thereto. While the vapour is passing through the column from plate to plate, its heat-content remains the same, but its composition changes, for it takes up low-boiling component a from

the reflux, and gives up to the latter high-boiling component *w*. This is shown in Fig. 6 at I 1, II 2, III 3, IV 4, V 5, and VI 6.

If, however, several reflux condensers are used, one being placed between every two successive plates, the vapour will still

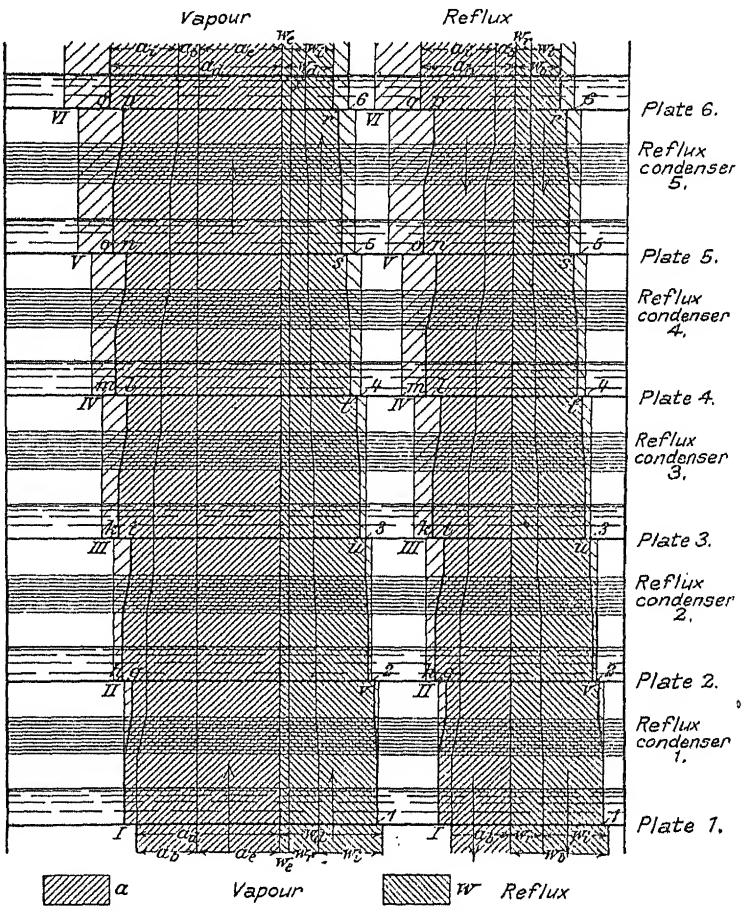


FIG. 6.—Graphic Representation of the Diminishing Amounts of Vapour and Liquid which ascend a Rectifying Column provided with a Reflux Condenser above every Plate.

enrich itself with low-boiling component on every plate, but a fraction of it will be condensed in each reflux condenser, and join the reflux, so that the total amount of vapour will become progressively smaller, as shown in *o*, *p*, *q*, *r*, *s*, *t*, *u*, *v*, *w*, 1.

If, in both cases, the amount of vapour rising from the boiling-vessel is equal to the amount of reflux descending into it, then in the second case the total amount of both in the column is much less than in the first case; in fact, towards the top of the column the total which accompanies the vapour $a_e + w_e$ is almost negligibly small.

With one reflux condenser the whole of the reflux circulates against the vapour throughout the column, but with several condensers the rising vapour loses *en route* the greater part of the material which would form the reflux: the amount of reflux gradually diminishes from bottom to top and becomes quite small.

The weight of vapour which passes through a plate in unit time is equal to the sum of the weight of reflux on the plate and the weight of final product recovered in unit time; and we know that for any one plate the richness of the product increases as the ratio—amount of reflux: amount of product—increases.

This can also be deduced from the equation that applies for each plate:

$$\frac{w_d}{a_d} = \frac{w_e + w_R}{a_e + a_R} = \frac{a_e f_e + a_R f_R}{a_e + a_R} = f_d.$$

The greater a_R is in proportion to a_e, the closer does f_d approach the value f_R; the smaller a_R is in relation to a_e the more nearly does f_d approach the value f_e. It follows that in the first case the composition of the vapour on any plate approaches that of the reflux on it, so that the composition of the vapour from the next higher plate is almost the same as if the reflux $a_R + w_R$ were the liquid from which that vapour was formed $(a_d + w_d)$. In the limiting case, therefore, the percentage of low-boiling component in the vapour increases from plate to plate almost as if the vapour generated on every plate were the original liquid from which the vapour on the next higher plate were evolved. If $a_R + w_R$ is small, then $a_e + w_e$ forms an important fraction of all the vapours, and these undergo very little change from plate to plate.

For the same heat-expenditure, a column provided with many condensers must have a greater number of plates; or, if the number of plates is unaltered, more heat must be expended.

The same conclusion follows from the following considerations:

Let us imagine two columns, one provided with a single reflux condenser, and the other with a condenser between every two consecutive plates. If both columns are required to rectify to the same extent with an equal number of plates, then the

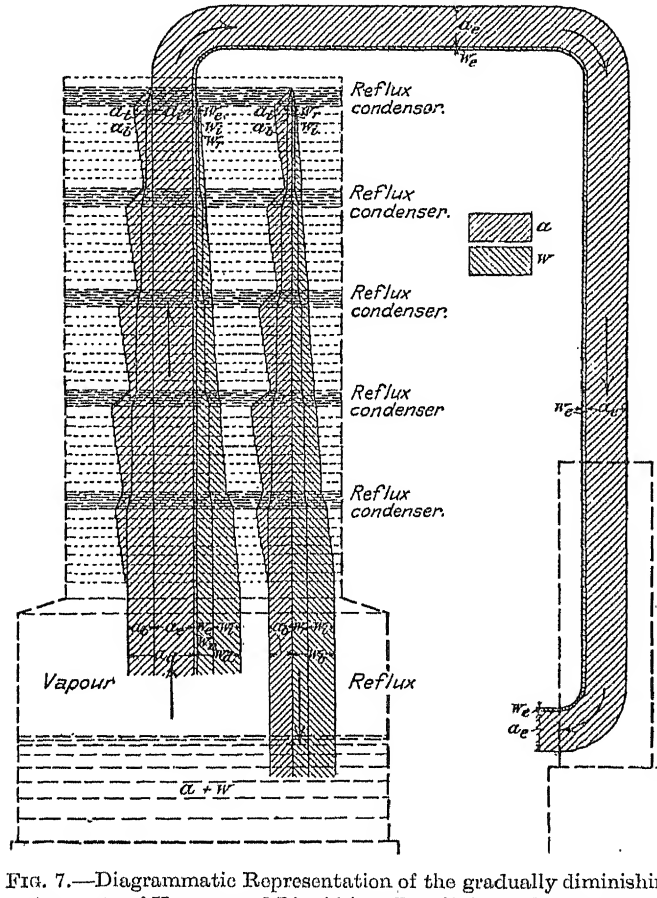


FIG. 7.—Diagrammatic Representation of the gradually diminishing Amounts of Vapour and Liquid in a Rectifying Column which is provided with a Reflux Condenser above every eighth Plate.

composition of the vapour rising from the boiling-vessel on to the lowest plate, and that of every vapour which is formed on the successive plates, must be the same for the two columns. In the column with one condenser above it, the vapours are enriched in low-boiling component solely by condensation and re-vaporisation; in the other column, the vapours are rectified

in each of the condensers, so that the condensate in each condenser has the same composition as that attained by the liquid on each plate in the first column. Therefore the boiling liquid on each plate in the second column is poorer than the liquid on the corresponding plate in the first column; and all refluxes from the plates are poorer. Hence, for the same output, the second column must consume more heat than the first, or it must be provided with a greater number of plates.

Thus we see that concentration of vapour is impeded by multiplying the parts where condensation occurs. Similarly, the use of a number of condensers inserted at greater intervals is nearly as disadvantageous; such an arrangement necessitates either higher columns or a greater expenditure of heat. Fig. 7 illustrates the disadvantage of this method of rectification.

8. SHOULD THE COLUMN BE PROTECTED AGAINST LOSS OF HEAT BY RADIATION; OR IS LAGGING UNNECESSARY?

After the foregoing explanations this question hardly needs an answer.

The heat radiated by the wall between the plates causes the liquid in contact with it to become cooled, *i.e.*, heat is lost; and the parts where the wall is in contact with vapour act as small reflux condensers in the manner described above, so that rectification is impeded, and either more plates or more heat must be used.

In Fig. 8, the outlines I, 1, VIII, 3 illustrate the operation of a column without loss of heat. Outlines I, 1, *o*, *p* show the effect of loss of heat by radiation, viz. condensation of vapours and progressive decrease in their amount from bottom to top.

Therefore in all cases it is better to protect the rectifying column against loss of heat.

A column whose internal temperature is 80–90° C. would lose about 900 kg. cals. per square metre per hour; and for a column 6 metres high and 1 metre diameter, the loss of heat would correspond with an unnecessary consumption of about 30 kg. of steam per hour. Hence the cost of lagging is quickly covered.

Numerical examples on this subject will be given in connection with calculations relating to apparatus for distilling and rectifying alcohol.

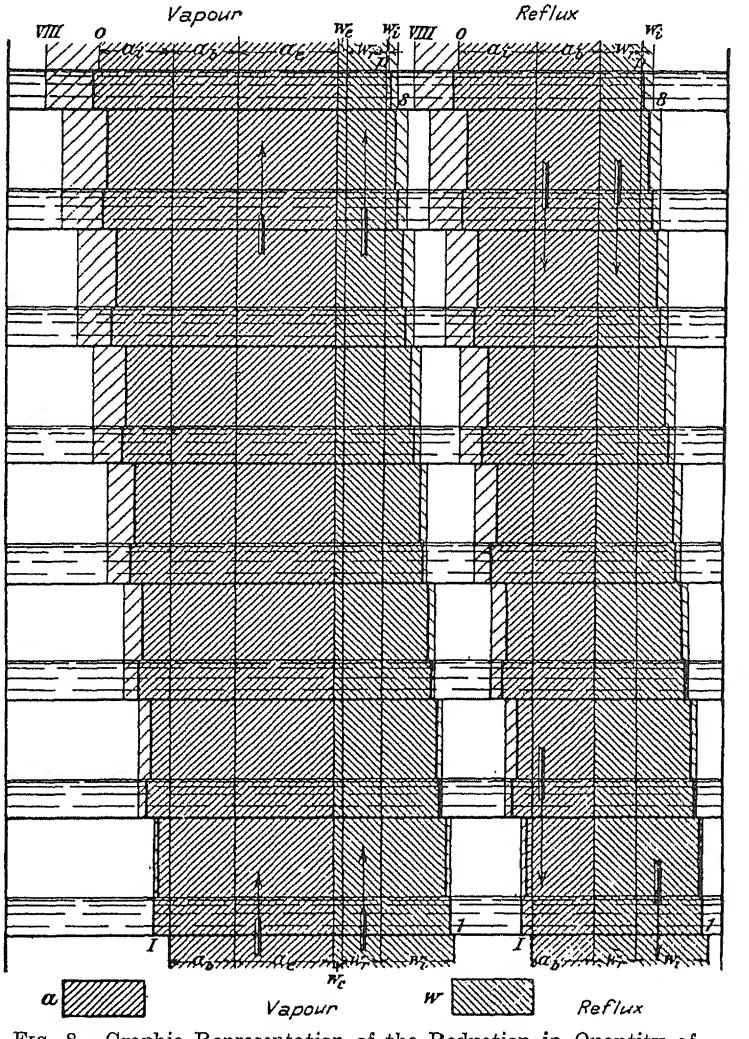


FIG. 8.—Graphic Representation of the Reduction in Quantity of Vapour and Liquid due to Loss of Heat by Radiation.

9. CAN THE LOW-BOILING COMPONENT OF A VAPOUR-MIXTURE BE SEPARATED MERELY BY CONDENSATION IN A SINGLE STAGE? (SEE ALSO SECTION 18.)

The smaller the fraction of a vapour-mixture that is condensed, the smaller is the amount of low-boiling component in the condensate. The first drops of the condensate have almost the same composition as the liquid from which the vapour-mixture was formed.

The greater the proportion of condensate (remaining in contact with the vapour), the greater the percentage of low-boiling component does it contain.

In the second case, the uncondensed vapour is certainly smaller in amount, but it is much richer in low-boiling component than the vapour in the first case.

If nearly all the vapour-mixture were condensed, the residual vapour would nearly attain the composition which it would have possessed had it been formed from a liquid identical with the original vapour-mixture.

Hence, by condensing almost completely in a single operation, we can never obtain more than a small quantity of final vapour whose composition is such that it might have been formed from a liquid identical in composition with the original vapour-mixture. Further, by condensing gradually, and by removing the small amounts of condensate as fast as they are formed, we can obtain a larger quantity of a richer final product; and the smaller the amount recovered at each stage, the easier is this result achieved.

If the fractional condensation of the original vapour-mixture proceeds continuously, and if the condensates are separated from the residual vapours as fast as they are formed, both condensates and residual vapours will become increasingly rich in low-boiling component. We may conceive that the total condensate has an average strength, expressed by the ratio $f_{R\,\text{mean}}$. Then in this case also the total weight of vapour $a_d + w_d$ is equal to the sum of the weight of the product $a_e + w_e$ and the weight of the total condensate $a_{R\,\text{mean}} + w_{R\,\text{mean}}$.

$$a_d + w_d = a_e + w_e + a_{R\,\text{mean}} + w_{R\,\text{mean}} \quad . \quad . \quad (32)$$

$$\frac{w_d}{a_d} = \frac{w_e + w_{R\,\text{mean}}}{a_e + a_{R\,\text{mean}}} = f_d \quad . \quad . \quad . \quad . \quad . \quad . \quad (33)$$

$$a_{R\,\text{mean}} = \frac{a_e(f_d - f_e)}{f_{R\,\text{mean}} - f_d} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (34)$$

$$C_R = \frac{a_e(f_d - f_e)(\alpha + f_{R\,\text{mean}}\,\beta)}{f_{R\,\text{mean}} - f_d} \quad . \quad . \quad . \quad . \quad (35)$$

Supposing we wish to separate by continuous condensation a definite weight of product $a_e + w_e$ $\left(\text{ratio } f_e = \frac{w_e}{a_e}\right)$ from a certain vapour mixture $a_d + w_d$ $\left(\text{ratio } f_d = \frac{w_d}{a_d}\right)$ of, at first, unknown weight; then, in order to ascertain the heat-expenditure that is required, we shall first have to find the mean value $f_{R\,\text{mean}}$, which must lie between the ratios of the liquids f_D and f_E, from which the vapours f_d and f_e were evolved. This mean value is not necessarily the arithmetic mean of f_D and f_E, because the relationship between composition of vapour and composition of liquid is by no means always a linear one. In the absence of a simple mathematical expression for this mean value, we must be content with an approximation, the value of which may be found from the vapour–composition curves.

When the value of $f_{R\,\text{mean}}$ has been determined, C_R, a_d, w_d, and all other related values follow immediately.

It will be seen that equation (35) is nearly identical with equation (24), which applies to rectifying columns with a single superimposed reflux condenser. In the latter equation f_R was the ratio of the reflux from any plate (f_B was the ratio of the reflux into the boiling-vessel), *i.e.*, it represented a liquid weak in low-boiling component, and often the weakest of all the liquids, and not, as here, the mean of the weak and strong refluxes. Therefore the numerical value of f_R (or f_B) is always greater than that of $f_{R\,\text{mean}}$, and consequently (as calculation shows), if other things are equal, C_R becomes much smaller when f_R is inserted in place of $f_{R\,\text{mean}}$. In other words, *the separation of liquids by continuous, gradual condensation is, up to a certain point, much less efficient than separation by the use of good rectifying columns in which the liquids are repeatedly brought to boiling-temperature.*

Numerical examples relating to the above are given in Section 18 and in Tables 21, 22, 28, 29 (Chart II).

10. SHOULD THE WHOLE OF THE REFLUX FROM THE REFLUX CONDENSER BE PASSED ON TO THE TOP PLATE OF THE COLUMN; OR IS IT BETTER TO DISTRIBUTE IT IN FRACTIONS OF DIFFERENT COMPOSITION OVER SEVERAL PLATES?

The vapour entering the reflux condenser comes from the liquid on the top plate of the column. Owing to the partial condensation of this vapour, the uncondensed portion of it (the product or final distillate) is richer in low-boiling component than the total vapour before condensation began, and the reflux is also richer in low-boiling component than the liquid on the top plate.

The reflux from the reflux condenser is, therefore, as a whole, always richer—though often only very little richer—than the liquid on the top plate.

If, as is possible with certain condensing arrangements, the reflux is drawn off in several fractions, then even the first and weakest fraction is richer in low-boiling component than the liquid on the top plate of the column.

The contention that the weak refluxes ("low wines," "phlegms") should be passed into the lower parts of columns, thereby keeping the upper parts free from them, is therefore unsound, for even these refluxes are not weaker than the liquid on the top plate.

We already know that separation proceeds more vigorously as the ratio amount of reflux: amount of product increases for each plate; consequently there is no doubt that the whole of the reflux from the reflux condenser should always be led on to the top plate.

11. VAPORISATION OF THE INITIAL CHARGE IN INTERMITTENT STILLS

A. Alcohol-content of the Residual Liquid in the Boiling-vessel

During rectification the amount of low-boiling component in the contents of the boiling-vessel is reduced almost to zero, because every kg. of low-boiling component that leaves the vessel is accompanied only by a definite, but very small, amount of high-boiling component. While low- and high-boiling components are

being vaporised from the boiling-vessel in constant weight and proportion, the residual liquid by no means retains its strength, for this diminishes at first more slowly, and later more quickly, than the absolute content of low-boiling component. Now since the production of 1 kg. of nearly pure low-boiling component requires more and more reflux heat as the solutions from which it is separated get weaker and weaker, it is obvious that the expenditure of heat for every kg. of low-boiling component must increase irregularly, slowly at first and very rapidly towards the end. In order to ascertain the total expenditure of reflux heat during the vaporisation of the whole of the charge in the boiling-vessel, it is necessary to determine the percentage of low-boiling component in the charge at frequent intervals (say, for every kg. distilled) throughout the distillation; then to find the reflux heat needed for every small fraction of low-boiling component that is vaporised; and finally, by adding together these separate amounts of heat, to find the total reflux-heat requirement.

If the charge in the boiling-vessel consists of a kg. of low-boiling and w kg. of high-boiling component, we can imagine that the low-boiling component passes into the cooler in x equal fractions, each represented by $\frac{a}{x}$, together with x equal fractions of high-boiling component, each of which weighs $\frac{a}{x} f_e$ kg. After n such fractions have been separated, the weight of low-boiling component left in the boiling-vessel is :

$$a_R = a - \frac{na}{x} = a\left(1 - \frac{n}{x}\right) = a\left(\frac{x-n}{x}\right) \text{ kg.} \quad . \quad . \quad (36)$$

and the weight of high-boiling component is :

$$w_R = w - \frac{na}{x} f_e = a\left(f - \frac{n}{x} f_e\right) \text{ kg.} \quad . \quad . \quad . \quad . \quad . \quad . \quad (37)$$

The percentage of low-boiling component left in the boiling-vessel (p_j) is therefore

$$\frac{100a\left(\frac{x-n}{x}\right)}{a\left(\frac{x-n}{x}\right) + w - \frac{na}{x} f_e} = \frac{100a\left(\frac{x-n}{x}\right)}{a + w - \frac{an}{x}(1 + f_e)} = p_j \quad (38)$$

The number of equal fractions (x) may be conveniently taken as 100, and, in order to keep the equation quite general, the

weight of the initial charge $a + w$ may be taken as 100 kg. The last equation then assumes the form :

$$\frac{100 - n}{(1 + f) - \frac{n}{100}(1 + f_e)} = p_j \quad . \quad . \quad . \quad . \quad (39)$$

where p_j is the percentage of low-boiling component left in the residue, after $\frac{na}{100}$ parts by weight of it have been distilled over.

If instead of calculating the percentage, we require the ratio $\frac{w_j}{a_j} = f_j$ of the residue, this is given by the equation

$$\frac{w - \frac{na}{x} f_e}{a - \frac{na}{x}} = f_j.$$

By replacing w by af, a is eliminated and we obtain

$$f_j = \frac{f - \frac{n}{x} f_e}{1 - \frac{n}{x}} \text{ or } f_j = \frac{f - \frac{n}{100} f_e}{1 - \frac{n}{100}} \quad . \quad . \quad . \quad . \quad (40)$$

If we know the original percentage of low-boiling component in the charge, and if, after distilling off some of it, we know the weight of low-boiling component remaining in the boiling-vessel, we can use the following equation for calculating the percentage of it in the residue :

$$p_j = \frac{100}{\frac{a(f - f_e)}{a_j} + f_e + 1} \quad . \quad . \quad . \quad . \quad (41)$$ [1]

[1] This equation is derived as follows :

$$a + w - (a_e + w_e) = a_j + w_j$$
$$a(1 + f) - a_e(1 + f_e) = a_j(1 + f_j)$$
$$a(1 + f) - (a - a_j)(1 + f_e) = a_j(1 + f_j)$$
$$a(1 + f) - a(1 + f_e) + a_j(1 + f_e) = a_j(1 + f_j)$$
$$a(f - f_e) = a_j(f_j - f_e)$$
$$a_j : a_j + w_j = p_j : 100$$
$$p_j = \frac{a_j 100}{a_j + w_j} = \frac{a_j 100}{a_j(1 + f_j)} = \frac{100}{1 + f_j}$$
$$f_j = \frac{100}{p_j} - 1$$
$$a(f - f_e) = a_j\left(\frac{100}{p_j} - 1 - f_e\right)$$
$$\frac{a(f - f_e)}{a_j} = \frac{100}{p_j} - 1 - f_e.$$

$$a_j = \frac{a(f - f_e)}{\frac{100}{p_j} - 1 - f_e} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (42)$$

where a is the weight of low-boiling component in the initial charge, f is its composition ratio, a_j the weight of low-boiling

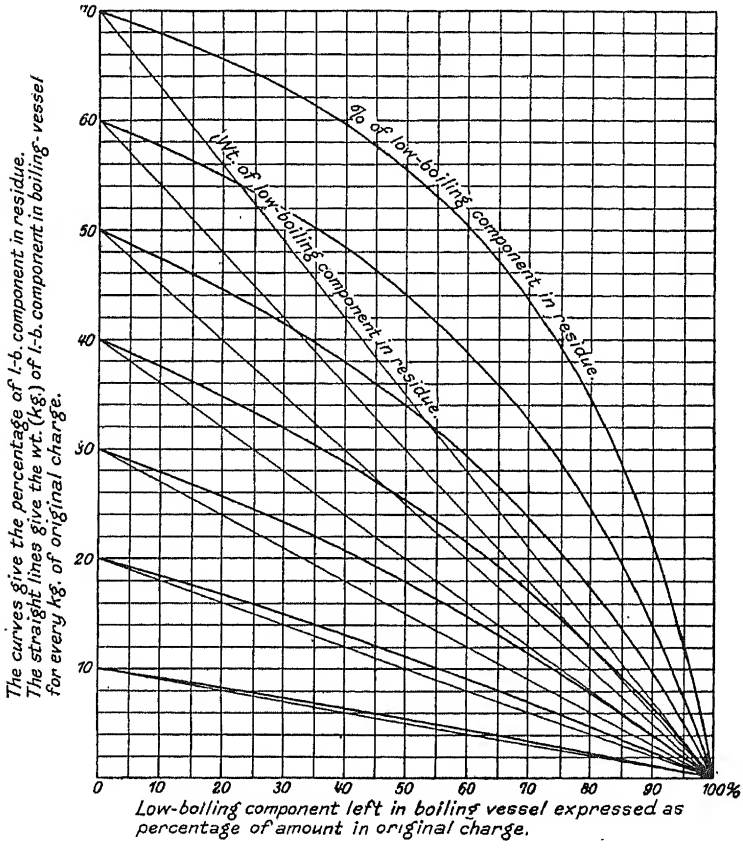


FIG. 9 (*cf.* Table 4).

component in the residue, f_e the composition ratio of the vaporised portion, and p_j the percentage of low-boiling component in the residue.

Equations (39) and (42) have been used for calculating the data given in Table 4. This table answers the questions: What is the percentage of low-boiling component in the residue

$(a_J + w_J)$ after 5–99 per cent. of this component has been distilled off? What is the corresponding weight in kg. of this component left in the boiling-vessel for every 70–10 kg. of it present in the original charge? The information given in the table is represented graphically in Fig. 9, where the horizontal axis gives the percentage of low-boiling component distilled over; and the vertical axis, for the curves, gives the percentage of that component left in the residue, and, for the straight lines, the weights of low-boiling components in the residue corresponding to a content of 70–10 per cent. in the original charge.

Equations (36) and (42) are applicable to the separation of all mixtures, irrespective of the nature of their components.

B. Reflux Heat needed during a Complete Distillation

In proportion as the residual mixture in the boiling-vessel becomes weaker in low-boiling component p_j, the reflux heat C_R required for every kg. of a_e becomes greater.

The amount of reflux heat C_B corresponding to each value of p_j which is required to produce 1 kg. of low-boiling component a_e, of predetermined purity f_e, from an initial charge f, can be obtained from the tables (*e.g.*, 11, 24, 31, 35, 40, 43, 47, 52); or it can be calculated from equation (26):

$$C_B = \frac{a_e(f_a - f_e)(\alpha + f_B\beta)}{f_B - f_e} \quad . \quad . \quad . \quad . \quad (43)$$

The sum of these separate heat-quantities gives the total reflux heat required to separate the whole of a from 100 kg. of initial charge.

Table 5 (p. 178) is to be used for initial charges containing 70–10 kg. per cent. of low-boiling component. The first column shows how many kg. of this component are present in the residue in the boiling-vessel. Columns 3 to 9 show the corresponding percentages of it in the residue (p_j): the amount of reflux heat C_B required in practice to distil off 1 kg. of alcohol, as 95 per cent. (wt.) spirit, from the mixture containing p_j per cent. given in the line above; and the total reflux heat needed for distilling over all the remaining alcohol, *i.e.*, down to a content of 0·01 per cent.

The data given in Table 5 are represented by graphs in Fig. 10. To take an example: if the original charge contained 50 per cent. of alcohol, *i.e.*, 50 kg. in 100 kg. of mixture, and 40 kg. was distilled over with a heat-expenditure of 1200 kg. cal. per kg. of alcohol, then the amount of heat needed to drive over the remaining 10 kg. is 25,575 kg. cal. If only 5 kg. was left in the boiling-vessel, 19,375 kg. cal. are required. The last 2 per cent. necessitates an expenditure of 15,025 kg. cal.

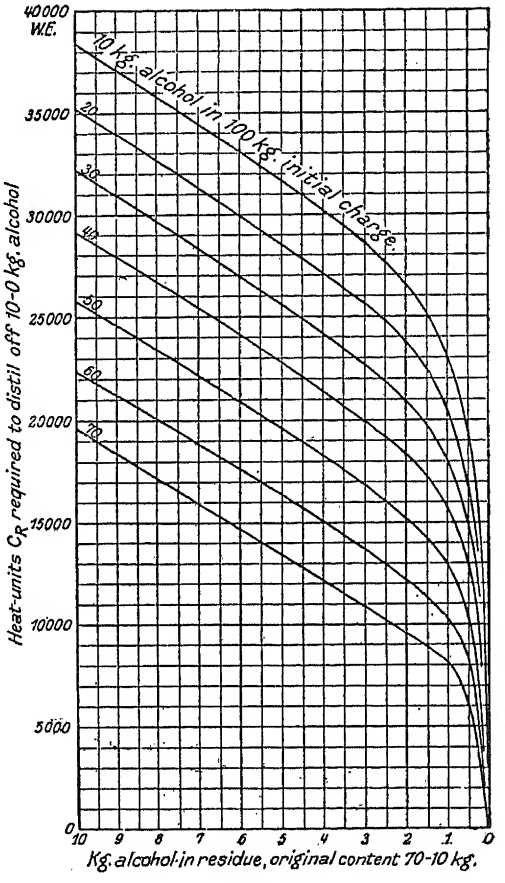


FIG. 10.

C. REFLUX HEAT REQUIRED AFTER RECHARGING

For many mixtures, *e.g.*, alcohol and water, the heat expended in reflux-formation, $C_R = C_B = C_V$, remains the same during the greater part of the distillation, because the high-grade mixtures on the top plates in the column need more reflux heat than the weaker liquids that are charged into the boiling-vessel. When the percentage of low-boiling component in that vessel has fallen to a certain point, the heat-requirement rises considerably and continuously, because weak charges always need more heat than charges of medium strength; with alcohol and water the change begins with a content of 12–13 per cent. alcohol (*v.* Table 11 for 94·61 per cent. spirit). This suggests that heat might, perhaps, be saved by adopting certain methods of working which would reduce the

total heat required to distil the whole of a mixture. For example, distillation could be continued until the contents of the boiling-vessel had attained the critical composition (12–13 per cent. alcohol) and then the vessel could be recharged; or the vessel could be replenished by continuously adding fresh mixture during the distillation. It can, however, be shown that

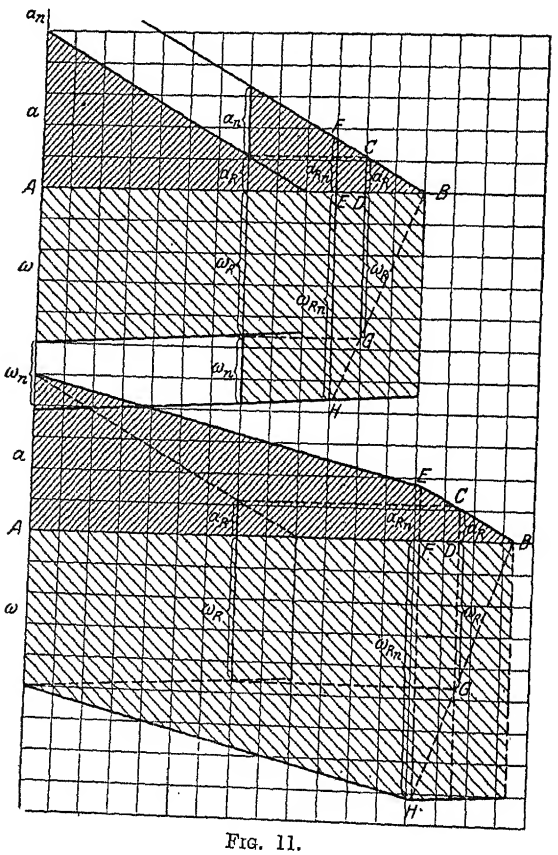


FIG. 11.

neither of these methods affects the amount of heat required. Calculated on the weight of low-boiling component recovered, the heat-requirement C_R is the same in all cases. This is best illustrated by means of two geometrical figures.

Fig. 11, upper part. At the start the boiling-vessel is filled with a kg. of low-boiling and w kg. of high-boiling component.

During rectification the amounts of these diminish to different extents until the residue contains only a_R and w_R, *i.e.*, until it is so weak that from then onwards more reflux heat is required. Then more of the original mixture is added so that $a_n + w_n$ is equal to the volume of liquid distilled off, *i.e.*, the boiling-vessel now contains the same volume of liquid as at the beginning. On further distillation a residue $a_{Rn} + w_{Rn}$ is left whose ratio is

$$\frac{w_{Rn}}{a_{Rn}} = \frac{w_R}{a_R}.$$

Then $$a_{Rn} - a_R : w_{Rn} - w_R = a_R : w_R$$
and the triangles being similar, it follows that

$$a + a_n : a_{Rn} = a : a_R$$
$$w + w_n : w_{Rn} = w : w_R.$$

That is, the amount of residue $(a_{Rn} + w_{Rn})$ requiring additional heat for its distillation remains proportional to the initial charge *plus* the added charge. There is no economy of heat.

Fig. 11, lower part. If the boiling-vessel is continuously replenished so as to maintain the critical content of low-boiling component (*v.s.*), the total heat-consumption is not altered: the surfaces representing the amounts of liquid to be distilled over remain proportional to the charges *plus* the recharges.

12. THE MEAN RATIOS OF THE RESIDUE f_{Rm} AND THE VAPOUR f_{dm} DURING THE DISTILLATION OF ALCOHOL-WATER MIXTURES

To determine practically the magnitude of the mean ratio of the residue in the boiling-vessel (and therefore also that of the vapour from it) during a definite and extended time, we must first find its value when portions of 1 kg. of alcohol and the water associated with it are successively vaporised from a known mixture. These ratios are given in Table 7. It is obvious, from columns 1 and 4 of this table, that the values for the percentage of low-boiling component left in the residue by no means run parallel with the corresponding absolute weights of alcohol remaining therein. In calculating the figures in Table 7, it was assumed that the composition of the vapour from the residue remained the same during the distillation of each fraction as it

was at the beginning, and this assumption involves no appreciable inaccuracy.

$$\frac{w}{a} = f \quad \frac{w - f_d}{a - 1} = f_R \text{ (because } a_d = 1) \quad . \quad . \quad . \quad (44)$$

Values of f_R are given in column 2.

The ratios of the vapours (f_d), given in column 3, follow directly from the ratios of the residues. The percentages of low-boiling component in the residues are derived as follows: If $a_R + w_R = 100$,

$$\frac{w_R}{a_R} = \frac{100 - a}{a} = f_R = \frac{100}{a} - 1 = f_R \quad . \quad . \quad (45)$$

Consequently, $a_R = \frac{100}{f_R + 1}$, where a_R is the percentage of low-boiling component in the residue.

From every such table of reciprocal values it is easy to find a percentage if the ratio of the mixture is known.

For greater accuracy, it has been assumed in Table 7 (col. 1) that from an alcohol-content of 15 parts per cent. by weight downwards the weight of alcohol in the same residue diminishes progressively by 0·5 kg., from 10 per cent. by only 0·25 kg., from 2 per cent. by 0·2 kg., from 1 per cent. by 0·1 kg., and from 0·1 per cent. by 0·02 kg. This must be remembered when the table is used.

To find the mean ratio of liquids whose alcohol-contents lie between two specified values, all the ratios between these chosen limits must be added together and their sum divided by their number. This method is, obviously, only applicable when there is a constant difference between the successive values of the alcohol-content.

For example: to find the mean value of f_R when the alcohol-content of the residue is reduced from 11 to 7·75 per cent. by weight.

$$\text{From 11 to 10 per cent. } f_R = \frac{3{\cdot}120 + 3{\cdot}253}{2} = 3{\cdot}1865.$$

$$\text{From 10 to 7·75 per cent. } f_R = \frac{32{\cdot}707}{9} = 3{\cdot}634.$$

$$\begin{array}{rl} 3{\cdot}1865 \times 1 & = 3{\cdot}1865 \\ 3{\cdot}6360 \times 2{\cdot}25 & = 8{\cdot}1765 \\ \hline 3{\cdot}25 & \dfrac{11{\cdot}3630}{3{\cdot}25} = 3{\cdot}497 = f_{Rm}. \end{array}$$

In Table 8 will be found the mean ratio of the residue for a number of alcohol–water mixtures; in this table the mean (theoretical) reflux heat C_R (taken from Table 11) is also given, because in rectification the reflux heat required to be set free in condensation depends upon the ratio of the liquid under consideration. In practice, however, and especially when high-grade products are desired, a greater amount of reflux heat must be provided in order to reduce the number of plates.

13. TWO-COMPARTMENT BOILING-VESSELS[1]

The boiling-vessels of rectifying apparatus designed to deal with weak products are sometimes fitted with a horizontal partition which divides them into two approximately equal compartments. After the residue of a previous distillation has been run from the upper nto the lower compartment of such apparatus, a new charge of the original mixture, more or less preheated, is introduced into the upper compartment, where it is heated by the vapour rising from the contents of the lower compartment (Fig. 12).

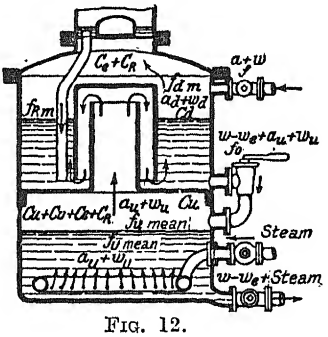


FIG. 12.

Let us first consider the distribution of low-boiling component in the contents of the two compartments.

In every distillation all the low-boiling component (a) that is introduced with the new charge must be expelled from the upper compartment (to be recovered as final product) together with the predetermined small portion of high-boiling component (w). Therefore, the rest of the last-named ($w - w_e$), and all the vapour (subsequently condensed) that came from the lower compartment to heat the liquid in the upper one, must remain in the upper compartment. This vapour must contain the whole of the low-boiling component that was present in the residue discharged from the upper into the lower compartment. It is safe to assume that the liquid left in the upper

[1] A valuable contribution on this subject was published by M. Pallaske in the *Mitteilungen des Vereins der* [illegible] *und Apparatenbauanstalt*, Nos. 762–767.

compartment retains but very little of the low-boiling component. When this liquid reaches the lower compartment it must be vaporised to such an extent that it becomes practically free of low-boiling component (containing about 0·01 per cent., the residue always being discarded as worthless), and its heat-content must suffice for preheating, reflux-forming, and producing the vapour of the final product in the upper compartment, *i.e.*,

$$C_u = C_v + C_e + C_R.$$

The quantities of heat required for preheating and for producing the final vapour, $C_v + C_e$, are known in every case :

$$C_v = a(\sigma + f\sigma_1)(t_o - t) \text{ and } C_e = a(\alpha + f_e\beta) \quad . \quad . \quad (46)$$

The reflux heat is, however, a variable quantity, since the amount of low-boiling component in the upper compartment diminishes from the start, viz., from f to fo.

$$C_R = \frac{a(f_{dm} - f_e)(\alpha + f_{Rm}\beta)}{f_{Rm} - f_{dm}} \quad . \quad . \quad . \quad . \quad (47)$$

where f_{dm} and f_{Rm} represent respectively the mean ratios of the vapour produced in, and the reflux contained in, the upper compartment (Fig. 11). The heat-quantity C_R increases continuously as each kg. of low-boiling component is removed as final product; its value can be found with the aid of Table 5.

The quantity of heat C_u needed to vaporise the whole of the liquid in the lower compartment is also variable : it increases as the liquid in that compartment becomes weaker.

$$C_u = C_v + C_e + C_R.$$

If all the low-boiling component $a(= a_e)$ is expelled from the upper part together with the small quantity of high-boiling component w_e $(= af_e)$, then all the low-boiling component that was discharged into the lower part (a_u), together with a large amount of w, viz. w_u (whose ratio $\frac{w_u}{a_u} = f_{u\,\text{mean}}$ increases continuously) must have risen into the upper part, leaving only high-boiling component w_A behind. The liquid run off from the

upper into the lower part has, therefore, the following composition :

$$w - w_e + a_u + w_u$$

$$\frac{af - af_e + a_u f_{u\,\text{mean}}}{a_u} = f_o$$

$$a(f - f_e) = a_u(f_o - f_{u\,\text{mean}})$$

$$a_u = \frac{a(f - f_e)}{f_o - f_{u\,\text{mean}}}$$

$$C_u = a_u(\alpha + f_{u\,\text{mean}}\beta)$$

$$C_u = \frac{a(f - f_e)(\alpha + f_{u\,\text{mean}}\beta)}{f_o - f_{u\,\text{mean}}} \quad . \quad . \quad . \quad (48)$$

Since the amounts of heat consumed in the lower and upper compartments are equal, it follows that :

$$a(\sigma + f\sigma_1)(t_o - t) + a(\alpha + f_e\beta) + \frac{a(f_{dm} - f_e)(\alpha + f_{Rm}\beta)}{f_{Rm} - f_{dm}}$$
$$= \frac{a(f - f_e)(\alpha + f_{um}\beta)}{f_o - f_{um}} \quad . \quad . \quad . \quad . \quad . \quad (49)$$

Obviously, a can be eliminated, and then the equation applies for 1 kg. of low-boiling component in final product or wash.

The first two expressions on the left-hand side are known in every case, as are also the first two factors $a(f - f_e)$ of the numerator on the right-hand side; but f_{Rm} and $\frac{\alpha + f_{u\,\text{mean}}\beta}{f_o - f_{u\,\text{mean}}}$ are unknown, because both of these involve average ratios, which cannot be known *a priori*, and still less so because the final composition of the residue above (f_o), which becomes the initial composition below, is also unknown. If f_o were known, the mean ratio of the vapour from below, $f_{u\,\text{mean}}$, could at once be calculated from the considerations advanced in the last section and the corresponding Tables 4 and 5; but as this is impossible, one has to proceed by way of trial and verification. To facilitate this operation, we have inserted Table 6, which gives the value of the mean ratio ($f_{u\,\text{mean}}$) of the contents of the lower compartment and of the vapour arising therefrom ($f_{u\,\text{mean}}$), when 50–1 per cent. mixtures are distilled to the limit 0·059 per cent. of alcohol. Table 6 also shows the ratio f_o, *i.e.*, the ratio when the lower distillation begins, and therefore also the difference $f_o - f_{u\,\text{mean}}$. Lastly, the numerical value of the fraction $\frac{\alpha + f_{u\,\text{mean}}\beta}{f_o - f_{u\,\text{mean}}}$ will be found in column 6.

The following examples illustrate the method of calculation :

Examples.—Alcohol-water mixtures of 50–10% strength are to be treated in rectifying apparatus fitted with two-compartment boiling-vessels. What is the alcohol-content in the upper compartment at the moment when the residue in it is run into the lower compartment? The specific heats of alcohol and water are $\sigma = 0{\cdot}8$ and $\sigma_1 = 1$, respectively. The distillate contains 85·7% by weight of alcohol (90% by volume). The results are brought together in Table 7.

Assuming that the original mixture $a + w$ must be heated from 20° to 100° C., *i.e.* through 80°, the value $C_v = (0{\cdot}08\sigma + f\sigma_1)$ for every kg. of alcohol recovered from 10–50% mixtures is found in Table 9, column 2. For 90% vol. mixtures, C_e is 298 kg. cal. per kg. of alcohol recovered (column 3). In column 4 is given the mean ratio f_{Rm} of the liquid in the upper part, the value being estimated from a preliminary trial-calculation; and in column 5 is shown the number of kg. cal., per kg. of alcohol, theoretically required for reflux formation, assuming that the provisionally found value of f_{Rm} is correct. Column 6 gives the sum of the values in columns 2, 3, and 5. Columns 7 and 8 show the values of $f - f_e$ and $\frac{1}{f - f_e}$, which are known in every case. Column 9 gives the products of the values in columns 6 and 8. Lastly, column 10 shows the alcohol-content of the liquid left in the upper compartment for discharge into the lower compartment; this value is found with the aid of Table 6, which gives the value of the factor $\frac{\alpha + f_{u\,\text{mean}}}{fo - f_u}$. This column, therefore, provides the answer to the question, *i.e.*, it gives the alcohol-content of the liquid which must be completely vaporised in the lower compartment (thereby losing almost all its alcohol) in order to supply sufficient heat (contained in the vapours) to the upper compartment for the separation of the product $a_e + w_e$ from the original mixture $a + w$. The lower part of Table 9 contains similar data for the production of 96·5% vol. spirit.

We must now apply the provisional solution to the example and find out if column 10 really gives the correct strength of the liquid discharged from the upper into the lower part. For this purpose Table 10 is given, the first column of which shows the alcohol-content of the original mixture, and the fourth column the heat-quantity $C_d = C_v + C_e + C_R$ required in the upper compartment for every 100 kg. of $a + w$. This quantity is obtained by multiplying the corresponding figure in column 6 of Table 9 by the number of kg. of alcohol contained in 100 kg. of $a_e + w_e$. The third column contains the mean ratio f_{um} of the vapour ascending from the lower compartment during the distillation; these figures are derived by interpolation from column 3 of Table 6.

The fifth column gives the value of the factor $\alpha + f_{um}\beta$ as calculated, and the sixth column its reciprocal.

Since $C_u = a_u(\alpha + f_{um}\beta) = C_d = C_v + C_e + C_R$, and C_d is given in column 4, a_u can now be found and inserted in column 7.

If a_u is known, so also is $w_u = a_u f_u$, values of which are given in column 8. The second column shows the weight of water $w - w_e$ which is left in the upper compartment after the product $a_e + w_e$ has been distilled over. The ninth column gives the sum of the weights of the components in the residual liquid left in the upper compartment, and the tenth column the reciprocal value.

And now, finally, it is possible to arrive at the percentage of alcohol in this residue, which is composed of water from above and vapour from below $(a_u + w_u + w - w_e)$; this value is given in the eleventh column.

The figures in column 11 of Table 10 agree well with those in column 10 of Table 9: *quod erat demonstrandum.*

14. UNINTERRUPTED SEPARATION OR CONTINUOUS DISTILLATION

In intermittent distillation the whole of the crude liquid mixture (which orten consists of three or more components) is charged into the boiling-vessel in one operation in order that during an extended period of operation the individual components may be separated as completely as possible *one after the other*. In continuous distillation, however, the apparatus is charged uninterruptedly with the mixture to be fractionated, and the separated components are delivered continuously and *simultaneously*.

An essential feature of the mechanism of fractionating columns is that each one can separate a mixture into only *two* fractions at the same time. A continuous column can separate a two-component mixture just as sharply and accurately as a periodic rectifying apparatus. If, however, the mixture has more than two components, the continuous type of column can separate only one of them satisfactorily, the others being obtained as mixtures; hence such a mixture can only be separated continuously by using two or more columns, and this makes the plant more complicated and more difficult to understand and operate. Since the considerations now to be advanced are of general applicability, the discussion will be confined to continuous apparatus for separating two-component mixtures. The method

of treatment used for periodic apparatus will also be followed here, but certain modifications will have to be introduced owing to the necessity for considering the temperature of the mixture as it enters the column, the transfer of heat to it so as to effect maximum economy of working, and the requirement that sometimes one, sometimes both of the components must be isolated in a state of purity.

We shall now discuss the actual conditions obtaining in the apparatus as well as the heat-consumption and the movements of liquids and vapours. We shall do this in a way that will be applicable to a large number of mixtures; and then we shall specially consider some mixtures whose physical properties are well known.

* * * * * * *

Excluding a number of special arrangements—to which the following considerations will also apply *mutatis mutandis*—two distinct types of apparatus for continuous separation have here to be considered, namely, those represented in Figs. 2 and 3 (p. 8). In Fig. 2, the rectifying (concentrating) column S is placed *above* the boiling-column A; in Fig. 3 these two columns are placed *side by side*. The second arrangement is adopted when vertical space has to be economised, or sometimes in order to obtain a weaker liquid (spent liquor) issuing from A. Operation and heat-consumption are the same for both.

In the second arrangement, a special column ("low-wine" column) must be placed below S for dealcoholising the reflux descending from S.[1]

In both cases, the mixture (wash) passes through a coil, or similar preheating device, in the preheater V, where it is heated by the vapours $(a_s + w_s)$ ascending from the rectifying column S; it then enters the boiling-column A, where it is gradually deprived of its alcohol; and it is finally drawn off from A as spent wash. Steam enters the boiling-column at its base, and the vapours leaving it rise into the rectifying column (S), where they are concentrated, and thence into the preheater (V), where they are partly condensed. The uncondensed vapour $(a_e + w_e)$ passes into the condenser or cooler (K) in which the product or distillate collects; the condensate in V flows back into the column S as reflux $(a_V + w_V)$. After leaving S, the reflux $(a_N + w_N)$ is

[1] This is, perhaps, best regarded as a part of S, viz. that part of it which is situated below the vapour-inlet.—(TRANSLATOR.)

completely deprived of its alcohol either in L (Fig. 3) or in A (Fig. 2); in the latter case it mixes with the wash (original mixture) and is distilled with it.[1]

15. BOILING-COLUMN WITH SUPERIMPOSED RECTIFYING COLUMN

In the arrangements shown in Figs. 2 and 3, the mixture $a + w$ flows on to M, the top plate of the boiling-column, with a temperature t_v which is usually below the boiling-point. Very frequently this mixture is preheated in the reflux condenser by the vapours ascending from the column, but as the temperature of these vapours is always lower than the boiling-point of the mixture, the latter will never be at boiling-temperature as it arrives on plate M.

The mixture $a + w$ can be preheated by heat-exchange with the spent wash, whose boiling-temperature is usually the higher; but this method is seldom used in Germany because it offers no appreciable advantages, and its adoption entails the use of more complicated and more costly apparatus.

Simultaneously with $a + w$, a vapour mixture, composed of a and w, rises in the column on to plate M. This vapour-mixture may be regarded as constituted of two parts:

(1) The first part, which is destined to heat the mixture $a + w$ on plate M from its initial temperature t_v to its boiling-temperature t_m, will be represented by $a_h + w_h$.[2] After this vapour has given up its latent heat to the mixture $a + w$ by condensing in it, it descends with the rest of the condensate from plate M. Let the quantity of heat imparted to $a + w$ by condensation of $a_h + w_h$ (which does not suffice to bring $a + w$ to the boiling-point) be represented by C_h. Then

$$C_h = a_h\alpha + w_h\beta \quad . \quad . \quad . \quad . \quad . \quad (50)$$

$$C_h = a_h(\alpha + f_h\beta) \quad . \quad . \quad . \quad . \quad . \quad (51)$$

[1] Mixtures are known which at certain concentrations produce vapours containing an excess of one component, whilst at other concentrations they produce vapours in which the other component is in excess. Such mixtures are more difficult to separate.

[2] The reader is reminded that small-letter suffixes refer to vapours and capital-letter suffixes to liquids.

(2) The remaining vapour ascending on to M from the mixture $a + w$ will be represented by $a_x + w_x$. Its heat-content is

$$C_x = a_x\alpha + w_x\beta \quad . \quad . \quad . \quad . \quad . \quad (52)$$
$$C_x = a_x(\alpha + f_x\beta) \quad . \quad . \quad . \quad . \quad . \quad (52\,a)$$

This heat is consumed not only in expelling from the boiling mixture $a + w = a_h + w_h + a_x + w_x$ the low-boiling component $a = a_e$ in the concentration required to yield the product $a_e + w_e$, but also in producing on M, for transmission to the rectifying column, sufficient additional vapour to secure this result (*i.e.*, production of a product of predetermined weight and strength). For this purpose the vapour $a_x + w_x$ must provide :

(*a*) the heat-quantity C_e for the formation of the product $a_e + w_e$ (or $a + w_e$) in vapour form, that is,

$$C_e = a_e\alpha + w_e\beta \quad . \quad . \quad . \quad . \quad . \quad (53)$$
$$C_e = a_e(\alpha + f_e\beta) \quad . \quad . \quad . \quad . \quad . \quad (54)$$

so that after C_x (derived from $a_x + w_x$) has expelled the fraction $a_e + w_e$ from the mixture $a + w$, there is left a liquid residue $w - w_e$, which joins the rest of the condensate from plate M.

(*b*) the vapour $a_x + w_x$ must also provide the vapour that accompanies $a_e + w_e$.

We have already seen that, in order to obtain a product rich in low-boiling component, it is necessary to provide a relatively weak vapour to accompany the pure vapour $a_e + w_e$ in the rectifying column : that this accompanying vapour is changed and concentrated by the reflux on every succeeding higher plate : and that this vapour itself forms reflux by condensation in the reflux condenser. We have also seen (Section 5) how this accompanying vapour completes a cycle in the space between every two successive plates by leaving the lower plate as vapour, condensing on the plate above, and returning as reflux to the lower plate, where it is again vaporised : and how during all these changes the heat-content remains the same for all the plates (losses due to radiation and other causes excepted) (*cf.* Fig. 5). The vapour which rises with $a_e + w_e$ from plate M on to the lowest plate of the rectifying column S must also flow back from it as liquid and return to plate M, where it will again be vaporised by the new vapour $a_x + w_x$. Let this

condensate be represented by $a_N + w_N$,[1] and its heat-content by C_N.

$$C_N = a_N\alpha + w_N\beta \quad . \quad . \quad . \quad . \quad . \quad . \quad (55)$$
$$C_N = a_N(\alpha + f_N\beta) \quad . \quad . \quad . \quad . \quad . \quad . \quad (56)$$

Accordingly, the vapour rising from M has the composition

$$a_e + w_e + a_N + w_N.$$

Therefore

$$C_x = C_e + C_N = a_e(\alpha + f_e\beta) + a_N(\alpha + f_N\beta) \quad . \quad (57)$$

(where $C_N = C_V = C_R$), and the total effective heat on plate M is

$$C_a = C_h + C_x = C_h + C_e + C_N = C_h + C_e + C_R \; . \quad (58)$$

The sum of C_h, C_e, and C_R does not quite represent the total heat-consumption in the boiling-column, and two small additional requirements have to be satisfied, namely :

(3) The heating of the spent wash. The liquid boiling on plate M has a lower temperature t_m than the spent wash, which leaves the boiling-column at temperature t_u and consists almost entirely of high-boiling component w. Consequently this spent wash must be heated up from t_m to t_u, and the heat required for this purpose is :

$$C_u = (w - w_e)(t_u - t_m)\sigma_1 \quad . \quad (59)$$

(4) Lastly, there is the unavoidable loss of heat C_{st} due to radiation from the walls of the apparatus; this will be discussed later.

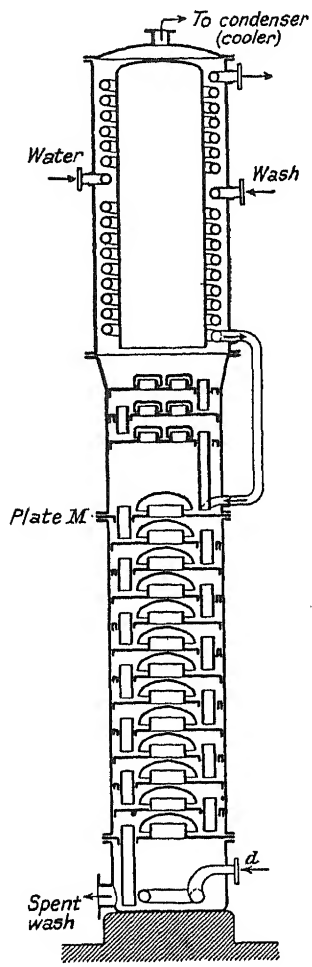


FIG. 13.

We have now to show how the required heat-expenditure

[1] $a_N + w_N$ is the reflux which descends from the bottom plate of the rectifying column on to plate M. The reflux from every other plate is symbolised by $a_R + w_R$, and the reflux from the reflux condenser by $a_V + w_V$.

and other quantities can be easily deduced when the ratios of the original liquid (f) and the product (f_e) are known.

From what has been said above it follows that the weights of vapour and liquid which reach plate M or are liberated on it are represented by

$$a + w + a_h + w_h + a_N + w_N + a_x + w_x - a_e - w_e - a_N - w_N \quad (60)$$

or,

$$w - w_e + a_h + w_h + a_x + w_x.$$

The composition ratio of this mixture is given by

$$\frac{w - w_e + w_h + w_x}{a_h + a_x} = f_M \quad . \quad . \quad . \quad . \quad (62)$$

On inserting the ratios

$$\frac{w}{a} = f \qquad \frac{w_e}{a_e} = f_e \qquad \frac{w_h}{a_h} = f_h \qquad \frac{w_x}{a_x} = f_x$$

we obtain

$$\frac{a(f - f_e) + a_h f_h + a_x f_x}{a_h + a_x} = f_M \quad . \quad . \quad . \quad . \quad (63)$$

Since $a_x + w_x$ and $a_h + w_h$ are parts of the same vapour, they must always have the same composition, so that f_x can be substituted for f_h

$$\frac{a(f - f_e) + (a_h + a_x)f_x}{a_h + a_x} = f_M \quad . \quad . \quad . \quad . \quad . \quad . \quad (64)$$

$$a(f - f_e) = (a_h + a_x)(f_M - f_x) \quad . \quad . \quad . \quad . \quad . \quad (65)$$

$$\frac{a(f - f_e)}{f_M - f_x} = a_h + a_x \quad . \quad . \quad . \quad . \quad (66)$$

$$a_h = \frac{C_h}{\alpha + f_x\beta} \qquad a_x = \frac{C_x}{\alpha + f_x\beta} \quad . \quad . \quad . \quad . \quad (67)$$

$$C_h + C_x = C_h + C_R + C_e = \frac{a(f - f_e)(\alpha + f_x\beta)}{f_M - f_x} \quad . \quad . \quad (68)$$

The last equation is important because it correlates the total heat-consumption and the composition of liquids and vapours on plate M. It cannot, however, be used for calculating specific mixtures unless, in addition to knowing the ratios f and f_e, we also know the heat-consumption $C_h + C_x$, and the composition of the liquid on M (*i.e.*, f_M), or that of the vapour f_x ascending on to it; and as a rule these quantities are not known.

The simple solution will now be given, and incidentally expressions will be found that show the relationships between the three individual parts of the total heat-consumption $C_R = C_V = C_N$, C_e, and C_h, and the composition of the vapours and liquids.

First, the heat of the reflux on plate M, *i.e.*, C_N. The vapour rising from M, whose ratio may be represented by f_m, consists of the vapour of the product $a_e + w_e$ and the vapour accompanying it, which has the same composition as the liquid flowing from the bottom plate of the rectifying column on to M ($a_N + w_N$). The vapour from M has therefore the composition $a_e + w_e + a_N + w_N$, and its ratio is :

$$\frac{w_e + w_N}{a_e + a_N} = f_m \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (69)$$

$$a_e f_e + a_N f_N = a_e f_m + a_N f_m \quad . \quad . \quad . \quad . \quad . \quad . \quad (70)$$

$$a_N = \frac{a_e(f_m - f_e)}{f_N - f_m} \quad . \quad . \quad . \quad . \quad . \quad . \quad (71)$$

But since

$$a_N = \frac{C_V}{\alpha + f_N\beta} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (72)$$

Therefore

$$\mathrm{C_N} = \mathrm{C_R} = \mathrm{C_V} = \frac{\mathrm{a_e(f_m - f_e)(\alpha + f_N\beta)}}{\mathrm{f_N - f_m}} \quad . \quad . \quad . \quad (73)$$

This important equation (73) is strictly analogous to equations (24) and (35).

C_N is the heat of the reflux $a_N + w_N$, and as the heat in the refluxes from all the plates is the same, C_N is equal to C_V, which represents the heat to be withdrawn in the reflux condenser from the vapour which arrives there from the rectifying column, in order that a product of ratio f_e containing low-boiling component a_e may be produced from a vapour of ratio f_M. For the same reason C_N is also equal to the heat of the reflux C_R from any plate.

Further, the latent heat of the product is given by the equation

$$C_e = a_e(\alpha + f_e\beta) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (74)$$

which may be expressed in the following form :

$$\mathrm{C_e} = \frac{\mathrm{a_e(f_M - f_x)(\alpha + f_e\beta)}}{\mathrm{f_M - f_x}} \quad . \quad . \quad . \quad . \quad (75)$$

Finally, a simple transformation of equation (68) gives us an expression which connects C_h with the weights and ratios of the liquids and vapours on plate M. [C_h is the heat required to warm

the original liquid $a + w$ from t_v, its temperature as it flows on to plate M, to t_m, the temperature of the boiling liquid on that plate.]

$$C_h = \frac{a_e(f - f_e)(\alpha + f_x\beta)}{f_M - f_x} - C_x \quad . \quad . \quad . \quad . \quad . \quad (76)$$

or, since

$$C_x = a_x(\alpha + f_x\beta) = \frac{a_x(\alpha + f_x\beta)(f_M - f_x)}{f_M - f_x} \quad . \quad . \quad (77)$$

$$C_h = \frac{\{a_e(f - f_e) - a_x(f_M - f_x)\}(\alpha + f_x\beta)}{f_M - f_x} \quad . \quad . \quad (78)$$

The sum of equations (73), (75), and (78) must naturally give equation (68), but inasmuch as f_M, f_x, f, f_N, and f_m are in general unknown, such addition has little practical value. A further assumption must be introduced before the equations can be solved.

Fortunately, this new assumption is one which simplifies the form of the equations and lightens the whole task: it is that the equations must apply to the optimum economic conditions. The effects of making this assumption on the equations, and on their solution, will now be demonstrated.

Those columns are economically the best which, for a given output, require the smallest expenditure for heating and cooling; and this is true even if their initial cost is somewhat greater than that of inefficient columns.

* * * * * * *

The total heat-requirement of apparatus for continuous separation will now be treated systematically from the standpoint of maximum economy of working. This heat-requirement is made up of the following items:

1. C_h, which is the heat needed for warming the original mixture from the temperature t_v attained in the preheater to the temperature t_m on the top plate M of the boiling-column

$$C_h = (a + w)\sigma(t_m - t_v) \quad . \quad . \quad . \quad . \quad (79)$$

in which σ is the specific heat of the liquid $a + w$. Unless special circumstances demand otherwise, it is obviously expedient to preheat the mixture $a + w$ in the reflux condenser (which is also the preheater), by means of the vapours ascending from the rectifying column, to a temperature as near t_v as possible, whereby less cooling water will be needed.

The amount of heat required to produce a given product from a known mixture depends on the composition of the liquid $a_N + w_N \left(f_N = \frac{w_N}{a_N}\right)$ that flows from the column into the boiling original mixture; and it is smallest when this reflux and the original mixture have the same composition (f_M). To be sure, this theoretical requirement cannot be quite fulfilled in practice, but it can be very nearly, as both experience and calculation show. To give the equations a practical form, we must assume that the reflux ratio f_N is identical with the ratio of the original mixture, f_M, but we must not forget that the actual heat-requirement will be a little greater than the theoretical minimum. The original equations (30), (35), (68), (73), (75), and (78) will retain their validity for all other special cases that involve different assumptions.

When the heat-consumption is the theoretical minimum, the reflux from the rectifying column has the same composition as the liquid on plate M, *i.e.*, $f_N = f_M$. Further, the vapours f_h and f_x ascending on to plate M have the same composition as the vapours which leave it; so that $f_h = f_x = f_m$. The fraction $a_x + w_x$ of the original vapour gives rise on plate M not only to the vapour of the product $a_e + w_e$, but to the vapour that is to form the reflux $a_N + w_N$. Therefore

$$C_x = C_e + C_N = a_e\alpha + w_e\beta + a_N\alpha + w_N\beta \quad . \quad . \quad (80)$$

$$C_x = a_x\alpha + w_x\beta = (a_e + a_N)\alpha + (w_e + w_N)\beta \quad . \quad . \quad (81)$$

and $$a_x = a_e + a_N \qquad w_x = w_e + w_N \quad . \quad . \quad . \quad . \quad (82)$$

Accordingly, in equation (78) $a_e + a_N$ may be substituted for a_x.

$$C_h = \frac{\{a_e(f - f_e) - (a_e + a_N)(f_M - f_x)\}(\alpha + f_x\beta)}{f_M - f_x} \quad . \quad (83)$$

Now the ratio of the vapour rising from plate M is:

$$\frac{w_e + w_N}{a_e + a_N} = \frac{a_e f_e + a_N f_N}{a_e + a_N} = f_m \quad . \quad . \quad . \quad . \quad (84)$$

$$a_N(f_N - f_m) = a_e(f_m - f_e) \quad . \quad . \quad . \quad . \quad . \quad . \quad (85)$$

$$a_N = \frac{a_e(f_m - f_e)}{f_N - f_m} \quad . \quad . \quad . \quad . \quad . \quad . \quad (86)$$

and further:

$$a_e + a_N = a_e + \frac{a_e(f_m - f_e)}{f_N - f_m} = \frac{a_e(f_m - f_e + f_N - f_m)}{f_N - f_m} \quad . \quad (87)$$

$$a_e + a_N = \frac{a_e(f_N - f_e)}{f_N - f_m} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (88)$$

On inserting this value of $a_e + a_N$ in equation (83), we obtain :

$$C_h = \frac{a_e\left[\dfrac{(f - f_e)(f_N - f_m) - (f_N - f_e)(f_M - f_x)}{f_N - f_m}\right](\alpha + f_x\beta)}{f_M - f_x} \qquad (89)$$

Assuming that the heat-consumption is a minimum (*cf. s.*), we put $f_N = f_M$ and $f_x = f_m$, and then, on multiplying out, we get :

$$C_h = \frac{a_e(f - f_M)(\alpha + f_m\beta)}{f_M - f_m} \quad . \quad . \quad . \quad . \quad (90)^1$$

This equation is very important for calculations relating to apparatus for continuous distillation ; it shows that, for minimum heat-consumption, the composition of the liquid on plate M, *and that of the vapour ascending from it, depend only on the heat required to warm the mixture $a + w$ on that plate ; it is the key to all calculations relating to this type of apparatus.*

Since a knowledge of the ratios f_M and f_m is of fundamental importance for the calculations, we must begin by evaluating equation (90).

The known terms in this equation are : the ratio of the original mixture $\frac{w}{a} = f$; its content of low-boiling component $a = a_e$; its heat-requirement $C_h = (a + w)\sigma(t_m - t_v)$; the latent

[1] This equation can, of course, be derived in a different way, viz., by putting $a_x = a_N + a_e$ at an earlier stage. In this case the ratio for the substances on plate M is :

$$\frac{w - w_e + w_h + w_N + w_e}{a_h + a_N + a_e} = f_M \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (91)$$

$$\frac{af - a_ef_e + a_hf_m + a_Nf_M + a_ef_e}{a_h + a_N + a_e} = f_M \quad . \quad . \quad . \quad . \quad . \quad (92)$$

$$a_e(f - f_e) = a_h(f_M - f_m) + a_N(f_M - f_M) + a_e(f_M - f_e) \quad . \quad (93)$$

$$a_e(f - f_e - f_M + f_e) = a_h(f_M - f_m) \quad . \quad . \quad . \quad . \quad . \quad . \quad (94)$$

$$\frac{a_e(f - f_M)}{f_M - f_m} = a_h = \frac{C_h}{\alpha + f_m\beta} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (95)$$

$$C_h = \frac{a_e(f - f_M)(\alpha + f_m\beta)}{f_M - f_m} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (96)$$

heats α and β of the substances a and w, and their specific heat σ.

As already stated, to economise heat, the mixture is usually preheated from its original temperature t to t_v in the reflux condenser by means of the vapour from the rectifying column (whose temperature t_s is known fairly accurately) up to within 10° or 8° of t_s ($t_N = t_s - 8$); or it is preheated to a temperature approaching t_a by heat-exchange with the spent wash.

The boiling-temperature t_m of the liquid on plate M can also be found approximately before calculating, because this liquid does not, as a rule, change much in composition during the distillation. But if a more accurate value of t_m be required, the calculation must be made a second time after the composition on plate M has been determined more accurately. In this way is found the heat C_h needed to effect the rise in temperature :

$$C_h = (a\sigma_a + w\sigma_w)(t_m - t_v) \quad . \quad . \quad . \quad . \quad (97)$$

This accomplished, equation (90) enables us to calculate the ratios f_M and f_m of the liquid and vapour on plate M, because these ratios are closely related (though there is no simple formula connecting them), and are known from experimental data relating to a considerable number of mixtures (*v.* Tables 2, 23, 30, 34, 39, 42, 46, 51).

In the absence of a mathematical expression correlating the composition of a liquid mixture with that of its vapour, it is impossible to solve equation (90) straight away; it can only be solved by inserting two corresponding values of f_M and f_m, derived from the tables, and repeating this operation until a pair of values is found which makes the right-hand side of the equation equal to the previously determined value of C_h.

2. The values of f_M and f_m being known, it is easy to deduce the amount of heat C_V that must be abstracted in the reflux condenser.

We know already that the total heat required for separating the components is :

$$C_a = C_e + C_h + C_V.$$

Therefore $$C_V = C_a - C_e - C_h \quad . \quad . \quad . \quad . \quad . \quad (98)$$

In this equation, C_e, the latent heat of the product, and C_h are always known. The total heat C_a is arrived at by inserting

in equation (68) the values of f_M and f_m found from equation (90).

$$C_a = C_e + C_h + C_V = \frac{a_e(f - f_e)(\alpha + f_m\beta)}{f_M - f_m} \quad . \quad . \quad (99)^1$$

Subtracting C_e and C_h from C_a:

$$C_V = \frac{a_e(f - f_e)(\alpha + f_m\beta)}{f_M - f_m} - a_e(\alpha + f_e\beta) - \frac{a_e(f - f_M)(\alpha + f_m\beta)}{f_M - f_m}.$$

On solving this equation we obtain another expression for the reflux heat:

$$C_R = C_V = \frac{a_e(f_m - f_e)(\alpha + f_M\beta)}{f_M - f_m} \quad . \quad . \quad . \quad (100)^2$$

This is the second important equation for use in calculations relating to apparatus for continuous separation. It is easily solved because the values of f_M and f_m are given in equation (90), and a, f_e, α and β are known *a priori*.

The reflux heat $C_V (= C_i + C_w)$ is usually abstracted from the vapour $a_s + w_s$ by *two* liquids, namely:

(*a*) the cold mixture $a + w$, whose temperature is raised from t to t_i by the heat-quantity C_i.

$$C_i = (a\sigma_a + w\sigma_w)(t_i - t) \quad . \quad . \quad . \quad . \quad (110)^3$$

[1] This equation must also result from the addition of equations (73), (75), and (90):

$$C_e + C_R + C_h = \frac{a_e[(f_M - f_x)(\alpha + f_e\beta) + (f_m - f_e)(\alpha + f_R\beta) + (f - f_m)(\alpha + f_M\beta)]}{f_M - f_m} \quad (111)$$

The numerator on expansion equals

$$\alpha(f - f_e) + \beta(f_M \cdot f_e + f_m f_R + f \cdot f_m - f_x f_e - f_R f_e - f_M f_m) \quad . \quad (112)$$

$$= \alpha(f - f_e) + \beta\big(f_e(f_M - f_R) - f_m(f_M - f_R) + f_m f - f_x \cdot f_e\big) \quad . \quad (113)$$

$$= \alpha(f - f_e) + \beta\big((f_M - f_R)(f_e - f_m) + f \cdot f_m - f_x f_e\big) \quad . \quad . \quad . \quad . \quad (114)$$

If in this equation we put $f_x = f_m$ and $f_R = f_M$, as we must for the case of minimum heat-consumption, we obtain ultimately:

$$C_e + C_R + C_h = C_a = \frac{a_e(f - f_e)(\alpha + f_m\beta)}{f_M - f_m} \quad . \quad . \quad . \quad (115)$$

[2] As already shown, this equation is valid, *mutatis mutandis*, for every plate in the column

$$C_R = \frac{a_e(f_d - f_e)(\alpha + f_R\beta)}{f_R - f_d} \quad . \quad . \quad . \quad . \quad . \quad (116)$$

where C_R is the reflux heat, f_R the ratio of the liquid on the plate, and f_d the ratio of its vapour.

[3] No equations numbered 101–109 appear in the original text, and there is a similar omission later on. It has been considered expedient to retain the numbering adopted by the author.—(TRANSLATOR.)

(*b*) water or other cooling agent, which takes up the heat $C_w = C_V - C_i$.

The original temperature of the cooling water, and the temperature to which it is to be raised in the reflux condenser, depend upon the circumstances of each particular case, including the circumstance whether the water is warm when it enters the reflux condenser, as it will be if it has been used for condensing the vapour of the product $a_e + w_e$ in the condenser (cooler)—a plan which is often found convenient. If, instead of cold water, such substances as air, boiling water, vapour, or liquefied gases are used, their properties have naturally to be taken into consideration.

It happens occasionally that, by preheating the original liquid $a + w$ up to its boiling-point, the heat extracted is sufficient to bring about the condensation and cooling of the vapour; in this case cooling water is not required.

If the preheating of the mixture $a + w$ is effected by the exhausted liquor and proceeds almost up to the boiling-point of the mixture, condensation in the reflux condenser must naturally be brought about with water alone.

3. The heat to be abstracted from the vapour of the product in the condenser (cooler) is made up of the heat to be taken from it during condensation :

$$C_e = a_e\alpha + w_e\beta \quad . \quad . \quad . \quad . \quad . \quad (117)$$

and the heat to be abstracted during cooling :

$$C_K = (a\sigma_a + w_e\sigma_w)(t_e - t_K) \quad . \quad . \quad . \quad . \quad (118)$$

The above are the three main heat-requirements in continuous distillation. There are, however, a few less important requirements which must be considered if the total heat-consumption is required.

4. C_u represents the heat required in the boiling-column to raise the temperature of the residue of the original mixture $(w - w_e)$ from t_m, the temperature on plate M, to t_u, the temperature of the " run-off " :

$$C_u = [(w - w_e)\sigma_w + (a_h + w_h)\sigma_h](t_u - t_m) \quad . \quad . \quad (119)$$

As the exhausted liquor is run off, its temperature t_u is above that of plate M, because it consists almost entirely of high-boiling component; and t_u is somewhat higher than the boiling-

point of w owing to the small excess pressure that exists in the columns. The magnitude of this pressure is determined by the number of plates, the depth and specific gravity of the liquid which the vapour has to penetrate, and by the back-pressure caused by friction between the vapour and the walls of the column, the reflux condenser, and the cooler. This back-pressure decreases from the bottom upwards in the apparatus, and on the average it amounts to 10–30 mm. of water for each plate. With aqueous solutions the temperature at exit is about 2° C. above the normal boiling-temperature. The progressive diminution in pressure causes a loss of heat, because the ascending vapour expands a little and does work. This loss is not, however, very appreciable, for the total difference in pressure seldom exceeds 1200–1400 mm. of water, which in the case of water-vapour corresponds to a heat-loss of about 0·06 per cent.

The average amount of secondary heat required in the boiling-column is given by :

$$C_u = [(w - w_e + w_h)\,\sigma_w + a_h\sigma_a]\,(t_u - t_m) \quad . \quad . \quad (120)$$

where σ_a and σ_w are the respective specific heats of the low- and high-boiling components.

5. The vapour that is condensed in the reflux condenser by abstraction of heat C_V, and whose temperature is lower than t_s, yields a liquid containing a higher percentage of low-boiling component than the liquid boiling on plate M; accordingly the latter liquid has a lower latent heat, a greater weight, and a lower specific heat than the former. This condensate from the reflux condenser must be heated from t_s to t_m as it flows down the column to plate M, and for this a heat-expenditure C_o is necessary :

$$C_o = (a_N\sigma_a + w_N\sigma_w)t_m - (a_V\sigma_a + w_V\sigma_w)t_s \quad . \quad . \quad (121)$$

C_o is determinable in every individual case, but as a rule only an approximate idea of its magnitude can be obtained because it varies within wide limits, varying with the physical properties and with the degree of separation of the components of the mixture.

Example 1.—To calculate the amount of secondary heat (C_o) needed in the boiling-column when 100 kg. of 99% methyl alcohol are produced with abstraction of 50,000 kg. cal. (C_V). Specific heat of pure methyl alcohol (σ) = 0·66; that of a 10–20% aqueous solution = 1·073. The boiling-

temperature at the top of the column (t_s) = 68°, and that of the liquid on plate M (t_m) = 95°.

Above: $a_V = 165$ kg. $w_V = 14{\cdot}31$ kg.
Below: $a_N = 1{\cdot}55$ kg. $w_N = 90{\cdot}17$ kg.

Therefore $(1{\cdot}55 \,.\, 0{\cdot}66 + 90{\cdot}17 \,.\, 1)95 - (165 \,.\, 0{\cdot}66 + 14{\cdot}31 \,.\, 1)68 = 294{\cdot}6$ kg. cal., *i.e.* about 0·51% of the reflux heat.

Example 2.—The specific heat of nitrogen (σ) = 0·430, and that of oxygen = 0·347. The upper temperature (T_s) = 78°, and the lower (T_m) = 79°. The reflux heat for 10 kg. of nitrogen of 99·5% purity = 1500 kg. cal.

Above: $n_V = 30{\cdot}48$ kg. $o_V = 1$ kg.
Below: $n_N = 6{\cdot}05$ kg. $o_N = 24{\cdot}01$ kg.

$$C_o = (6{\cdot}05 \,.\, 0{\cdot}43 + 24{\cdot}01 \,.\, 0{\cdot}347)79 - (30{\cdot}48 \,.\, 0{\cdot}43 + 1 \,.\, 0{\cdot}347)78$$
$$= 863{\cdot}65 - 1049{\cdot}36 = -187{\cdot}71 \text{ kg. cal.}$$

In this case, therefore, heat is not consumed, but evolved.

* * * * * * *

We have now to consider the relation between the heat required to warm the reflux and the progress of the concentration of vapour and reflux.

The specific heat of the low-boiling component of a mixture can be either less or greater than that of the high-boiling component (*e.g.*, alcohol 0·66, water 1·0, nitrogen 0·430, oxygen 0·347), and when the low-boiling component is in excess, more heat may be required for the reflux in the upper part than in the lower; and the reverse may be the case, according to the physical nature of the components. If the weight and composition of the reflux were the same on all the plates, it would be easy to calculate the heat-units required, but as this is not so, and it would be far too tedious to calculate the exact conditions on every plate, an approximation appears to be justified. If the reflux issuing from the reflux condenser ($a_V + w_V$) is at temperature t_V, and the reflux flowing on to plate M ($a_N + w_N$) at temperature t_N, we may assume the existence of an average reflux which requires the following amount of secondary heat in the rectifying-column:

$$C_o = \left(\frac{a_V + a_N}{2}\sigma_a + \frac{w_V + w_N}{2}\sigma_w\right)(t_N - t_V) \quad . \quad . \quad (122)$$

6. The heat lost by radiation from the walls of the apparatus C_{st} is, as explained in Section 8, always an absolute loss. The loss of heat per hour from each square metre of surface for every

degree centigrade difference in temperature between the unprotected surface and the surrounding air is, for

Copper	5–6·5 kg. cal. approx.
Wrought iron . . .	8–9 ,, ,, ,,
Cast iron	9–10 ,, ,, ,,

A good lagging material loses about 5–6 kg. cal. per sq. metre per hour. The variations for each material depend on movements in the surrounding air.[1] Since the difference in temperature between a well-lagged surface and the air is only about one-sixth to one-eighth of that between the unprotected surface and the air, the lagging can save about 70–85 per cent. of the loss of heat radiated from bare walls. The actual loss of heat, calculated on a given yield, must be computed for each individual apparatus, because it decreases as the size of the apparatus increases. Some idea of the loss may be gathered from the statement that a copper apparatus for distilling alcohol, with an hourly capacity of 1000 litres of wash, would lose 3000 kg. cal. per 100 litres of spirit produced, if unlagged, and 600 kg. cal. if lagged; but if the capacity were 10,000 litres the respective losses would be only 600 and 120 kg. cal. The heat consumed in producing 100 litres of spirit would be about 9000 to 12,000 kg. cal., *i.e.*, the loss would amount to 6·67 and 1 per cent., respectively.

The following is a short summary of heat-requirements of a distilling apparatus of the continuous type provided with superimposed columns:

Heat to be applied at the base of the boiling-column:

$$C_g = C_e + C_V + C_h + \frac{C_o + C_u + C_{st}}{2} \quad . \quad . \quad . \quad (123)$$

or

$$C_g = C_e + C_i + C_w + C_h + \frac{C_o + C_u + C_{st}}{2} \quad . \quad (124)$$

or

$$C_g = C_h + C_x + \frac{C_o + C_u + C_{st}}{2} \quad . \quad . \quad . \quad . \quad . \quad (125)$$

or

$$C_g = C_a + \frac{C_o + C_u + C_{st}}{2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (126)$$

[1] For a discussion of heat-losses and lagging materials see the author's work: "Verdampfen, Kondensieren und Kühlen" (Evaporating, Condensing, and Cooling). Sixth edition, pp. 294, 311.

Heat required for heating and vaporising on plate M :

$$C_h + C_x + C_o + C_{st} = C_h + C_V + C_e + C_o + C_{st} \quad . \quad (127)$$

Heat abstracted in the reflux condenser :

$$C_i + C_w = C_V = C_R = C_N \quad . \quad . \quad . \quad . \quad (128)$$

Heat removed in the condenser (cooler) :

$$C_e + C_K \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (129)$$

In the distillation of aqueous mixtures, steam is often blown in directly at the base of the boiling-column, where it mixes with and gives up its latent heat C_a to the exhausted liquor, the temperature of the run-off being t_u; for example, if $t_u =$ 102° C., 1 kg. of steam will give up 637 — 102 = 535 kg. cal. If the heat is conveyed by conduction along metallic surfaces, as it must be along the cooling surfaces of the reflux condenser and cooler, the necessary areas of these surfaces must be determined by applying the laws of conduction, for which purpose the author's work referred to above may be found useful.

The considerations already advanced apply also to distillation under increased or reduced pressure, but in these cases the slightly altered conditions arising from the physical condition of the substances must be taken into account.

In the above exposition, no comprehensive examples have been given, because it appeared wiser to postpone them to a later portion of this work, where the method of calculating the data for distilling apparatus will be treated in a thorough and systematic way.

16. THE NUMBER OF PLATES REQUIRED IN THE COLUMNS

A. The Rectifying Column

The equation

$$C_R = \frac{a_e(f_d - f_e)(\alpha + f_D\beta)}{f_D - f_d} \quad . \quad . \quad . \quad . \quad (130)$$

gives the amount of heat required by the reflux to produce a final distillate $a_e + w_e$ from a liquid of ratio f_D and its vapour f_d. If we insert in it a sufficient number of corresponding values of f_D and f_d, taken from Tables 2, 23, 30, 34, 39, 42, 46, 57 and

Charts V and XIV (which give actual figures found by experiment), we find that for many mixtures C_R increases *continuously* as the content of low-boiling component in the initial mixture decreases. We learn that, in general, the weaker the original liquid, the greater is the amount of heat required to produce from it a definite weight of a definite product $(a_e + w_e)$ (*cf.* Tables 24, 35, 43, 47, 58). But C_R does not increase *continuously* for all mixtures: there are some which do not follow the above rule exactly, and for which the required reflux heat undergoes wide fluctuations. In such cases quite weak mixtures require, per kg. of low-boiling component, very large amounts of reflux heat; and these amounts diminish as the content of low-boiling component increases, until a certain minimum value of C_R is reached. If then the alcohol-content of the solution further increases, the value of C_R increases also (Tables 11, 31, 43, 62). These fluctuations in C_R are determined by the nature of the substances and by the form of their vapour-composition curves.

Such properties and peculiarities must, of course, be considered in calculating the dimensions of apparatus required for specific purposes, and for mixtures whose composition ratios lie between $\frac{w}{a}$ and $\frac{w_e}{a_e}$, the *highest* value of C_R must be taken as the basis of calculation.[1]

Example.—Ethyl alcohol and water. Table 11 tells us that the amount of reflux heat C_R required to produce 1 kg. of 94·6% alcohol from a 1% mixture is 5050 kg. cal.; from a 36% mixture, 258 kg. cal.; and from a 92% mixture, 807 kg. cal.

The table shows further that *at least* 773 kg. cal. must be set free in the reflux condenser in order to obtain 1 kg. of alcohol from a crude spirit of any strength down to 7%; and if the spirit is still weaker, considerably more reflux heat is required.

We have seen, in Section 15, that in addition to the main reflux heat C_R, smaller amounts of heat C_o and C_{st} are required in the rectifying column to heat the reflux from t_s to t_m, and to compensate for radiation losses, although the latter are very

[1] The total heat required to yield a product $a_e + w_e$ from a boiling liquid mixture of ratio f_D and its vapour f_d is:

$$C_d = C_e + C_R = \frac{a_e(f_D - f_d)(\alpha + f_e\beta)}{f_D - f_d} + \frac{a_e(f_d - f_e)(\alpha + f_D\beta)}{f_D - f_d} \quad (131)$$

$$= \frac{a_e(f_D - f_e)(\alpha + f_d\beta)}{f_D - f_d} \quad (132)$$

small when the columns are well lagged. These small quantities of heat C_o and C_{st} are supplied to the apparatus at its lowest point, partly as components of C_a and C_x (together with C_h, C_e, C_R), where they, like C_R, take their full part in the work of concentration. But their concentrating action gradually diminishes, because they are consumed in the manner stated, and ceases completely at the top plate of the columns. In actual practice it is almost impossible to calculate exactly the decrease of concentrating action as the column is ascended, and therefore we shall assume that one-half of the sum of these two heat-quantities is operative on each plate, and that this may be added to C_R.

The actual consumption of heat in the rectifying column is therefore

$$C_e + C_R + \frac{C_o + C_{st}}{2} \quad . \quad . \quad . \quad . \quad . \quad (133)$$

As stated previously, $C_o + C_{st}$ seldom amounts to more than 1–2 per cent. of C_R.

In calculating the number of plates required in a rectifying column, we may either start from the bottom, *i.e.*, plate M, or from the top, *i.e.*, the reflux condenser; we shall select the latter plan because it is somewhat quicker. By using the maximum value of the reflux heat [1] and working downwards, we arrive in time at plates upon which the mixtures are so weak that this value only just suffices to yield the product desired. Finally, the calculated difference in strength of the liquids on two successive plates becomes vanishingly small and the calculation is finished (*cf.* Tables 13, 19, 25, 32, 36, 40, 44, 49, 58, 62, and, particularly, Charts VI, VII, X, XII). It would be unpractical to include more plates in the calculation in order to achieve results of almost negligible value.

The method of calculation will be best understood from the examples given in subsequent sections; in this place it will merely be indicated.

1. The percentage strength of the reflux f_r is obtained directly from the percentage strength of the vapour of the product f_e (Tables 2, 22, 30, 34, 41, 42, 46, 51), because the reflux is the origin of this vapour.

[1] It should not be forgotten that the reflux-heat requirement does not always increase *pari passu* with diminishing content of low-boiling component.

2. The equation $C_V = a_V\alpha + w_V\beta = a_R\alpha + w_R\beta$, in which C_V, α, and β are known, gives the values of a_V and w_V $(= a_V f_V)$, *i.e.*, the weights of the components of the reflux.

3. By adding to a_V and w_V the weights of the components of the final vapour, a_e and w_e, we obtain the weights of the components of the vapour which is evolved from the top plate of the column $(a_s + w_s = a_e + w_e + a_V + w_V)$, and hence the ratio f_s and the percentage strength.

4. From f_s we can deduce the composition of the liquid mixture $a_s + w_s$ on the top plate, this liquid being the source of the vapour.

5. The reflux from the top plate has the same composition as the liquid upon it, viz., fs.

6. The weights of the components of this reflux are given by the equation: $C_R = a_R(\alpha + f_R\beta)$.

7. The composition of the vapour ascending on to the top plate is obtained from the composition of the reflux from it: $a_d + w_d = a_e + w_e + a_R + w_R$; and so on.

The greater the amount of reflux heat C_R that is used to obtain a given yield of product, the smaller is the number of plates required. The smallest expenditure of heat necessitates the greatest number of plates, and *vice versa*.

B. The Boiling-column

Much of that which has been said for the rectifying column applies also to the boiling-column.

The total heat concerned in the operation of this column, C_g, is made up of the heat of the product C_e, that required for heating on plate M C_h, the reflux heat C_R, the secondary heat C_o, C_u, and the radiated heat C_{st}.

$$C_g = C_e + C_h + C_R + \frac{C_o + C_{st} + C_u + C_{st}}{2} \quad . \quad (134)$$

Since in this case also the heat needed for raising the temperature of the exhausted liquors from t_m to t_u and the radiated heat are gradually lost, the concentrating action of $C_u + C_o + C_{st}$ must also be considered.

The value of C_u may vary considerably, because it depends upon the mixing proportions and the properties of the components of the original liquids, but it will seldom exceed 3–6 per cent. of the total heat C_g.

The effective heat in the boiling-column

$$C_a = a_a(\alpha + f_e\beta) \quad . \quad . \quad . \quad . \quad . \quad (135)$$

produces on every plate the vapour $a_d + w_d$ of ratio f_d, which changes in composition at each level in the column. This weight of vapour $a_d + w_d$ must also be condensed on every plate and flow downwards from it; and all the original mixture which does not proceed upwards to form the product $w - w_e$ will join it in its downward path at plate M and at plates beneath M. If the separation is perfect this reflux will consist entirely of high-boiling component. If f_R denote the ratio of this total reflux

$$\frac{w - w_e + w_d}{a_d} = f_R \quad . \quad . \quad . \quad . \quad . \quad (136)$$

$$w - w_e = a_d f_R - w_d = a_d f_R - a_d f_d \quad . \quad . \quad . \quad (137)$$

$$a_d = \frac{w - w_e}{f_R - f_d} \quad . \quad . \quad . \quad . \quad (138)$$

$$C_a = \frac{(w - w_e)(\alpha + f_d\beta)}{f_R - f_d} = C_e + C_h + C_R \quad . \quad . \quad (139)$$

The last equation is of importance for boiling-columns: it shows the connection between heat-content and vapour-composition on every plate, in relation to the weight of exhausted liquor $(w - w_e)$.[1]

The richer the vapour f_d on the upper plates of the column is required to be, the greater the amount of heat must it contain. This equation also shows the maximum richness of vapour which can be attained in a boiling-column by the expenditure of a definite amount of heat for a definite weight of $w - w_e$.

After solving a sufficient number of examples by means of this equation, it will be seen that if a certain amount of heat C_a be introduced into the bottom part of a boiling-column to heat a given amount of reflux $(w - w_e)$, the content of low-boiling component will increase at each successive level until it reaches a definite maximum f_R and f_d, which is given in the equation. If the heat-expenditure is limited, it is not possible to obtain in the upper levels a vapour of *any* required composition, but only of a certain maximum composition f_d. The richer the vapour desired, the greater the heat-expenditure C_a.

[1] In all the Tables (18, 19, 27, 31, 33, 37, 41, 43, 45, 48, 50, 52, 58, 62, 68) which give heat-quantities $C_a = C_e + C_h + C_R$ required for specific mixtures, the weight of the exhausted liquor $w - w_e$ has been taken as 100 kg.

If, on the basis of a definite heat-expenditure for a given weight of high-boiling fraction $w - w_e$, the data for a boiling-column be calculated from its base upwards, it will be seen that both vapour and reflux become richer, quickly at first and then more slowly, until concentration practically ceases at the point when its strength is the highest possible under the conditions. This fact alone makes it appear expedient to start the calculation from the bottom; but the procedure suggested is further justified by the circumstance that at this stage a small but definite loss must be admitted and made the basis of the calculation; the extent of this loss can be assumed within certain limits. No column can be operated, or its data calculated, without allowing for a little loss, because a liquid consisting only of one substance cannot possibly produce a vapour which contains two substances. But in the calculation the loss can be made as small as desirable, and the smaller it is made the greater will be the number of plates—or heat-expenditure—required.

In the calculations to be considered later, the amount of low-boiling component in the exhausted liquor, *i.e.*, the loss, is assumed to be 0·01 per cent. Whether this figure represents a large or a small loss, depends upon the amount of high-boiling component in the original mixture. If, for example, the high-boiling exhausted liquor represents 50 per cent. of the original charge and contains 0·01 per cent. of low-boiling component, the loss is 0·01 per cent. of the theoretical yield of low-boiling component; but if the exhausted liquor represents 95 per cent. of the original charge, then the 0·01 per cent. of low-boiling component carried away with it represents a loss of 0·2 per cent. of the total theoretical yield of low-boiling component.

The procedure to be followed in calculating the number of plates required in a boiling-column is as follows:

1. The percentage amount of low-boiling component to be left in the exhausted liquor as it is run off from the column must be fixed; this gives the value of f_a, *i.e.*, the percentage amount in the vapour evolved from that liquid.

2. The heat C_a which is operative in the boiling-column is known from previous considerations or calculations, and therefore by using the equations

$$C_a = a_a(\alpha + f_a\beta) \text{ and } w_a = f_a a_a$$

the weights of a_a and w_a in the vapour from the spent liquor can be calculated.

3. The reflux from the bottom plate consists of condensed vapour $a_a + w_a$ and the spent liquor $w - w_e$; its ratio is therefore

$$\frac{w - w_e + w_a}{a_a} = f_R.$$

4. From f_R we can at once deduce the ratio f_d of the vapour which rises from the lowest plate (the ratio of the liquid on this plate is also f_R); this vapour is, of course, somewhat richer than the vapour from the spent liquor. Its weight is calculated from equation (139). In a similar way the ratio of the vapour ascending from the second plate is derived from the composition of the reflux upon that plate $a_{d_1} + w_{d_1} + w - w_e$, and its weight is known; and so on for the vapours from the other plates.

Continued calculation shows that after the amount of low-boiling component in the vapour has increased up to a certain point, depending on the ratio of C_a to $w - w_e$, the increase gradually diminishes and finally almost vanishes. In this way is found the attainable upper limit of vapour-concentration under the given conditions.

* * * * * * *

At the beginning of this Section we learnt that by starting the calculation at the top of a *rectifying column*, designed to deliver a definite product by the expenditure of a definite reflux-heat C_R, a plate is always reached upon which the boiling liquid contains an amount of low-boiling component that is the lowest possible under the conditions prescribed; a weaker liquid could only be obtained by using a greater reflux-heat C_R. Expressed in other words: the value of C_R taken as the basis of the calculation is the theoretically smallest which must be used to obtain the desired product from a liquid as weak as that present on the last plate which enters into the calculation.

On the other hand, in the case of a *boiling-column*, for which the heat-expenditure C_a is proportioned to the weight of exhausted liquor, by starting the calculation from the bottom we never meet with more than one plate containing a mixture of the desired strength. In other words: the value of C_a chosen as the basis of the calculation is the smallest which can be expended on a liquid almost devoid of low-boiling component to secure ultimately a product of the desired concentration.

The following, therefore, is obviously the goal we are aiming at: to establish such a relation between the heat-quantities C_R and C_a that the maximum strength to be attained in the boiling-

column by expenditure of heat C_a is precisely that which will lead to the production of the desired product in the rectifying column with a heat-expenditure of C_R. *This is the main point of the foregoing considerations.*

In the tables given later, which show how the results vary with the heat expended, the effective heat in the rectifying column (C_R) always refers to 1 or 10 kg. of low-boiling component a, and the heat in the boiling-column (C_a) to 100 kg. of the high-boiling spent-liquor ($w - w_e$).

17. THE RECTIFYING COLUMN IS PLACED ALONGSIDE THE BOILING-COLUMN

When the rectifying column is placed side by side with the boiling-column (Fig. 3), the mixture $a + w$, preheated to t_v in the reflux condenser, flows on to the top plate M of the boiling-column, just as it does when the rectifying column is situated above. On plate M this mixture is heated from t_v to t_m by the heat C_h which is supplied by the vapour $a_h + w_h$ rising on to this plate. Accompanying $a_h + w_h$ is the vapour $a_x + w_x$, of the same composition, the heat of which vaporises a from the mixture $a + w + a_h + w_h$, and also that fraction of w which is needed to form the vapour-mixture $a_m + w_m (= a + w_m)$. The substances arriving on, and leaving M (either as vapour or reflux) cause the formation on it of a mixture whose ratio f_M is

$$\frac{w - w_m + w_h + w_x}{a + a_h + a_x - a} = f_M \quad . \quad . \quad . \quad . \quad (141)$$

Since w_x, a_x, w_h, a_h are all parts of the same vapour, $\frac{w_x}{a_x} = \frac{w_h}{a_h} = f_x = f_h$, and therefore equation (141) can be written:

$$\frac{a(f - f_m) + (a_h + a_x)f_x}{a_h + a_x} = f_M \quad . \quad . \quad . \quad . \quad . \quad (142)$$

$$a(f - f_m) + (a_h + a_x)f_x = (a_h + a_x)f_M \quad . \quad . \quad (143)$$

$$\frac{a(f - f_m)}{f_M - f_x} = a_h + a_x \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (144)$$

$$a_h = \frac{C_h}{\alpha + f_x\beta} \quad a_x = \frac{C_x}{\alpha + f_x\beta} \quad . \quad . \quad . \quad . \quad . \quad (145)$$

$$C_h + C_x = \frac{a(f - f_m)(\alpha + f_x\beta)}{f_M - f_x} \quad . \quad . \quad . \quad . \quad . \quad (146)$$

$$C_h = \frac{a(f - f_m)(\alpha + f_x\beta)}{f_M - f_x} - a_x(\alpha + f_x\beta) \quad . \quad . \quad (147)$$

Since the whole of the low-boiling component a must leave the boiling-column, a_x must be equal to a.

$$C_h = \frac{a(f - f_m - f_M + f_x)(\alpha + f_x\beta)}{f_M - f_x} \quad . \quad . \quad . \quad (148)$$

This equation, which is of general validity, gives the relation between the heat (C_h) required to warm the original mixture $a + w$ from t_v to t_m and the composition of the mixture on plate M; it also shows that the latter depends solely on the magnitude of C_h. For the case of minimum heat-consumption, the compositions of two successive vapours may be taken as equal and f_x put equal to f_m; we then obtain the equation

$$\mathbf{C_h = \frac{a(f - f_M)(\alpha + f_m\beta)}{f_M - f_m}} \quad . \quad . \quad . \quad . \quad (149)$$

which, as was to be expected, corresponds to equations (90) and (96) for superimposed columns. In each case C_h is known (*cf.* equation 79), because it depends only upon the preheating temperature t_v, which can be selected at will, and the boiling-temperature t_m on plate M, which is also known. Consequently, the composition of the liquid f_M and that of the vapour from it, f_m, are easily derived from equation (149); and the solution of this equation forms the starting-point for calculating the data of all apparatus for continuous separation.

The effective heat in the boiling-column comprises C_h and that required to produce the vapour f_m, which we have denoted by C_x. We have

$$C_x = a(\alpha + f_m\beta) = \frac{a(\alpha + f_m\beta)(f_M - f_m)}{f_M - f_m}$$

therefore,

$$C_h + C_x = \frac{a(f - f_M + f_M - f_m)(\alpha + f_m\beta)}{f_M - f_m} \quad . \quad (150)$$

$$\mathbf{C_h + C_x = \frac{a(f - f_m)(\alpha + f_m\beta)}{f_M - f_m}} \quad . \quad . \quad . \quad . \quad . \quad (151)$$

To ascertain the total heat-expenditure in the boiling-column, we must also consider the heat C_u needed to warm the liquid $w - w_e + a_h + w_h$ from t_m to the exit-temperature t_u, and the heat lost by radiation C_{st}, the values of which we have already decided to reduce by one-half for the purpose of calculation.

$$C_a = C_h + C_x + \frac{C_u + C_{st}}{2} \quad . \quad . \quad . \quad . \quad (152)$$

In every case it is possible to determine the values of $C_u + C_{st}$ with considerable accuracy; their sum seldom exceeds 3–8 per cent. of $C_h + C_z$.

The operation, and also the calculation, of a boiling-column are quite independent of the product to be won; they depend solely on the composition and temperature of the original liquid.

The vapour $a + w_m$ flows down from the boiling-column to the top plate L^1 of the lower part L of the rectifying column.* From this plate it rises through the rectifying column S, parts with a portion of its contents in the reflux condenser, leaving the remainder to appear in the condenser (cooler) as the final product. The vapour $a + w_m$, therefore, returns the portion $w_m - w_e$ from the reflux condenser to the rectifying column. The condensate formed in the reflux condenser (by abstraction of heat C_R) must obviously contain both a and w in such proportions that the product $a_e + w_e$ can be evolved from it as vapour. As, however, the latent heat of $w_m - w_e$ is not sufficient for this purpose, further vapour $a_z + w_z$ must be added to the vapour $a + w_m$ on plate L^1. When the reflux $a_N + w_N$ from the bottom plate of the rectifying column S reaches plate L^1, it is at once re-vaporised, partly by the heat of the vapour $a_z + w_z$, and partly by that of the vapour $w_m + w_e$. Plate L^1, therefore, receives and gives up the following weights of materials:

$$a + w_m + a_z + w_z - a - w_e + a_N + w_N - a_N - w_N \,. \qquad (153)$$

and the ratio of the liquid on plate L^1 is

$$\frac{w_m - w_e + w_z}{a_z} = f_{L'} \quad . \quad . \quad . \quad . \quad . \quad . \qquad (154)$$

Since

$$w_m = af_m = a_e f_m \quad . \quad . \quad . \qquad (155)$$

it follows that

$$a_e f_m - a_e f_e + a_z f_z = a_z f_{L'} \quad . \quad . \quad . \quad . \quad . \qquad (156)$$

$$a_e(f_m - f_e) = a_z(f_{L'} - f_z) \quad . \quad . \quad . \qquad (157)$$

Now we know that

$$a_z(\alpha + f_z\beta) = C_z$$

Therefore,

$$a_z = \frac{C_z}{\alpha + f_z\beta},$$

and so we find generally that the heat C_z to be added in the

* There is no suitable English equivalent for the German word *Luttersäule*, which connotes the section of the rectifying column situated below the vapour-inlet. In the German text both the *Luttersäule* and the top plate in it are indicated by the letter L; to avoid confusion in the translation the former is represented by L and the latter by L^1.—(TRANSLATOR).

rectifying column to the vapours coming from the boiling-column is calculable from the equation

$$C_z = \frac{a_e(f_m - f_e)(\alpha + f_z\beta)}{f_{L'} - f_z} \quad . \quad . \quad . \quad . \quad (158)$$

For the optimum case, in which the vapours ascending from two successive plates are identical, $f_m = f_z$, and consequently $f_{L'} = f_M$, and

$$C_z = \frac{a_e(f_m - f_e)(\alpha + f_m\beta)}{f_M - f_m} \quad . \quad . \quad . \quad . \quad (159)$$

The vapour $a_z + w_z$ containing the heat C_z must be provided from the lower section L of the rectifying column, so that this section is always required when the columns are placed side by side; like the boiling-column, its function is to remove the alcohol from the liquid which flows into it from S, although in the present case the amount of liquid is usually smaller than that present in boiling-columns. The reflux heat $C_V = C_R$, liberated in the reflux condenser and present in the rectifying column S, is greater than C_z by the amount of the latent heat of $w_m - w_e$, for the latter is already in the vapour form as it comes from the boiling-column. Consequently, the heat to be abstracted in the reflux condenser is $C_V = C_z + (w_m - w_e)\beta$ (where $w_m = a_m f_m$ and $w_e = a_e f_e$).

$$C_V = \frac{a_e(f_m - f_e)(\alpha + f_m\beta) + (a_m f_m - a_e f_e)(f_M - f_m)\beta}{f_M - f_m}$$

$$C_V = \frac{a_e(f_m - f_e)(\alpha + f_M\beta)}{f_M - f_m} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (160)$$

As was to be expected, this equation is precisely similar to the corresponding equation (73) for apparatus with superimposed columns.

In addition to the heat lost by radiation C_{st}, we have to consider the heat required in the rectifying column to raise the temperature of the reflux from t_v to $t_{L'}$. This heat, designated C_o, amounts to about 3–5 per cent. of C_R; and both it and C_{st} will be halved, for the reasons already given, in calculating the number of plates required. In the section L, we have to include, besides C_z and C_{st}, the heat C_u needed for the secondary heating of the reflux from $t_{L'}$ to t_u. In determining the total heat-consumption of this section we shall use half-values of C_o and C_u (corresponding respectively to 2 and 1·5–3 per cent. of C_z).

The heat required in the boiling-column is

$$C_a + \frac{C_u + C_{st}}{2} = \frac{a(f - f_m)(\alpha + f_m\beta)}{f_M - f_m} + \frac{C_u + C_{st}}{2} \quad . \quad (161)$$

and that required in section L of the rectifying column is

$$C_z + \frac{C_o + C_u + C_{st}}{2} = \frac{a(f_m - f_e)(\alpha + f_m\beta)}{f_M - f_m} + \frac{C_o + C_u + C_{st}}{2} \quad (162)$$

The total heat-requirement is therefore

$$C_g = C_a + C_z = \frac{a(f - f_e)(\alpha + f_m\beta)}{f_M - f_m} + \frac{C_u + C_o + C_u + C_{st} + C_{st}}{2} \quad (163)$$

These equations are in every respect analogous to those deduced for apparatus with superimposed columns. In both arrangements the heat-consumption is the same, except for one small difference, namely, that with adjacent columns a little more heat is needed to compensate for that lost by radiation from section L.

18. GRADUAL VAPORISATION OF LIQUID MIXTURES AND GRADUAL CONDENSATION OF VAPOUR MIXTURES

A. Gradual Vaporisation

When from a mixture of two liquids $a + w$ a portion $a_d + w_d$ is vaporised, the vapour produced may either remain in contact with the residual liquid $a_R + w_R$, or it may be separated immediately and uninterruptedly from it.

(*a*) The following equations are valid for the case in which all the vapour produced remains in contact with the residual liquid :

$$\begin{aligned} a + w - a_d - w_d &= a_R + w_R \\ a(1 + f) - a_d(1 + f_d) &= a_R(1 + f_R) \\ a_R &= a - a_d \\ a(1 + f) - a_d(1 + f_d) &= a(1 + f_R) - a_d(1 + f_R) \\ a_d(f_R - f_d) &= a(f_R - f) \end{aligned}$$

The weight of the liberated vapour $a_d + w_d$ is

$$a_d = \frac{a(f_R - f)}{f_R - f_d} \qquad w_d = a_d f_d \quad . \quad . \quad . \quad (164)$$

and the heat required to liberate it is

$$C_d = \frac{a(f_R - f)(\alpha + f_d\beta)}{f_R - f_d} \quad . \quad . \quad . \quad . \quad (165)$$

Since the ratios f_R and f_d of the liquid and vapour are known, or can be determined, for every mixture, we can use the equations to calculate any of the other values provided that we know the latent heat C_d, or the weight of a that is vaporised, or the composition of the vapour f_d, or that of the residual mixture f_R.

Example. To calculate the strengths of the vapour evolved and of the liquid residue, and the heat consumed when 1 kg. of methyl alcohol is evolved as vapour from 100 kg. of a mixture containing 90 kg. of water and 10 kg. of methyl alcohol.

We use the data in Table 23 to ascertain which values of f_R and f_d will satisfy equation (164). After trial we find that $f_R = 9{\cdot}86$ and $f_d = 1{\cdot}28$.

$$a = 10,\ w = 90,\ f = \frac{90}{10} = 9.$$

$$a_d = 1 = \frac{10(f_R - 9)}{f_R - f_d} = \frac{10(9{\cdot}86 - 9)}{9{\cdot}86 - 1{\cdot}28} = \frac{8{\cdot}6}{8{\cdot}58} = 1 \text{ kg.}$$

$$w_d = 1\,.\,1{\cdot}28 = 1{\cdot}28 \text{ kg.}$$

$$\left.\begin{aligned} a_R &= 9{\cdot}0 \text{ kg.} \\ w_R &= 88{\cdot}72 \text{ kg.} \end{aligned}\right\} 9{\cdot}22\%.$$

$$C_d = \frac{10(9{\cdot}86 - 9)(255 + 1{\cdot}28\,.\,550)}{9{\cdot}86 - 1{\cdot}28} = 961,$$

i.e., the vapour evolved contains 43·8% and the residual liquid 9·22% of methyl alcohol; the heat consumed is 961 kg. cal.

(*b*) If the vapour produced is separated at every instant from the residual liquid, the alcohol-contents of both residue and vapour change continuously, both becoming weaker and weaker. At every instant

$$\frac{w}{a} = \frac{w_d + w_R}{a_d + a_R} = f = \frac{a_d f_d + a_R f_R}{a_d + a_R}.$$

The ratio f_d does not, however, remain constant during any given period, but it is the mean of the compositions of the first and last fractions of vapour; it may therefore be written

$$a_d f + a_R f = a_d f_{d\,\text{mean}} + a_R f_R$$

$$a_R = \frac{a_d(f - f_{d\,\text{mean}})}{(f_R - f)} \quad a_d = \frac{a_R(f_R - f)}{(f - f_{d\,\text{mean}})} \quad . \quad . \quad (166)$$

or, since

$$a_d = a - a_R$$

therefore

$$af - a_R f + a_R f = a f_{d\,\text{mean}} - a_R f_{d\,\text{mean}} + a_R f_R$$

$$a_R = \frac{a(f - f_{d\,\text{mean}})}{(f_R - f_{d\,\text{mean}})} \quad a_d = \frac{a(f_R - f)}{f_R - f_{d\,\text{mean}}} \quad . \quad . \quad (167)$$

$$C_d = \frac{a(f_R - f)(\alpha + f_{d\,\text{mean}}\beta)}{f_R - f_{d\,\text{mean}}}.$$

Now these equations could be easily used to calculate any required value if the mean composition f_{dm} of the evolved vapour could be treated as a function of the (known) compositions of the original and final liquids; but as this cannot be done we must either adopt the unsafe method of estimating this value from the experimental data given in tables and curves, or the more reliable method of calculating it step by step. In the example given both methods can be used.

Example.—100 kg. of a mixture containing 10 kg. methyl alcohol and 90 kg. water are distilled with immediate removal of the vapour until the residual liquid contains 5% of methyl alcohol. To calculate the heat-consumption, and the weights of vapour and residual liquid.

$$f = \frac{90}{10} = 9 \quad f_R = \frac{95}{5} = 19.$$

$$C_d = \frac{10(19 - 9)(255 + f_{dm} \times 550)}{(19 - f_{dm})}.$$

Chart III shows that the mean composition of the vapours from a 5% and a 10% methyl alcohol-water mixture is approximately the arithmetic mean. Therefore

$$\frac{28{\cdot}6 + 46{\cdot}8}{2} = 37{\cdot}7\%, \text{ therefore } f_{d\,\text{mean}} = 1{\cdot}652.$$

The heat-consumption is approximately

$$C_d = \frac{10(19 - 9)(255 + 1{\cdot}652 \times 550)}{19 - 1{\cdot}652} = 6707 \text{ kg. cal.}$$

The total weight of vapour produced:

$$\left.\begin{aligned} a_d &= \frac{10(19 - 9)}{19 - 1{\cdot}652} = 5{\cdot}764 \text{ kg.} \\ w_d &= \phantom{\frac{10(19 - 9)}{19 - 1{\cdot}652}} = 9{\cdot}522 \text{ kg.} \end{aligned}\right\} 37{\cdot}70\%.$$

$$a_d + w_d = 15{\cdot}286 \text{ kg.}$$

The residual liquid:

$$\left.\begin{aligned} a_R &= 4{\cdot}236 \text{ kg.} \\ w_R &= 80{\cdot}418 \text{ kg.} \end{aligned}\right\} 5\%$$

$$a_R + w_R = 84{\cdot}654 \text{ kg., or } 84{\cdot}654\% \text{ of } a + w.$$

* * * * * * *

Instead of estimating the mean strength of all the vapours, it is more accurate—or less inaccurate—to perform the calculation in stages, for example, to find the values of the factors f_R, a_d, a_R corresponding to successive reductions of 1 per cent. in the strength of the residual liquid. Values obtained by this method are given in Tables 21 and 28.

Column 8 of Table 28 shows that when a 10 per cent. methyl-alcohol mixture is vaporised until the residual liquid contains 5 per cent. of alcohol, this liquid represents only 66 per cent. of the weight of the original mixture, and not 84·654 per cent., as found above. If the vaporisation is quite continuous and regular, the weight of the residue will be found to be even a little less than this.

The value of the mean ratio $f_{d\,\text{mean}}$ of vapours from mixtures of widely differing composition can approximately be determined by calculation on the assumption that it is the arithmetic mean of the limiting ratios; and this method is not too inaccurate provided that these limiting vapours are not essentially different.

In calculating the values given in Tables 21 and 28 it was assumed that at every stage in the vaporisation there was a constant difference of 1 per cent. between the alcohol-contents of the liquid mixture and the residue from it, and also that the mean ratio of all the vapours evolved during each stage was the arithmetic mean of the ratios of the initial and final vapours (column 3).

The weight of alcohol in the residue and the weight of the total residue at the end of each stage are given in columns 4 and 6, the original alcohol-content being 1 kg. Columns 7 and 8 give the weights of residue after ten stages. The numbers in column 7 were obtained by multiplying the first number in column 4 by the second number in column 6: by multiplying the first two numbers in column 4 by the third number in column 6: by multiplying the products of the first three numbers in column 4 by the fourth number in column 6: and so on for the ten successive stages. Since the numbers in column 6 are valid for $a = 1$, those in column 7 apply for continuously diminishing values of a ($0{\cdot}940 \times 0{\cdot}943 \times 0{\cdot}944$). Lastly, column 10 (Table 21) gives the weight of residue, expressed as a percentage of the weight of the original mixture (50 per cent.); the numbers in this column were obtained similarly to those in column 7, but whereas in the latter $a = 1$ at the beginning of each series of ten stages, in column 10 a decreases continuously throughout. We learn from Tables 21 and 28 that if we wish to separate all the alcohol from an alcohol-water mixture by simple distillation, we must vaporise practically the whole of the mixture; in other words, simple distillation should not be used for separating alcohol and water.

Chart II shows that the percentage of alcohol in the residue decreases practically *pari passu* with the weight of the residue

(expressed as a percentage of the original mixture), and that the removal of the last of the alcohol from a mixture containing less than 3 per cent. of it, involves the concomitant vaporisation of much water.

B. Condensation in Stages

If the vapour $a_s + w_s$ of an alcohol-water mixture be condensed in stages, and if each condensate be removed immediately and completely, both the residual vapour $a_e + w_e$ and the condensate $a_V + w_V$ become richer and richer in alcohol. Assuming, as we did for gradual vaporisation, that the mean composition of the condensates from two *very similar* vapours is the arithmetic mean of the ratios of the two condensates at the end of a stage, then

$$\frac{w_s}{a_s} = \frac{w_e + w_V}{a_e + a_V} = f_s = \frac{a_e f_e + a_V f_V}{a_e + a_V}$$

$$a_e f_s + a_V f_s = a_e f_e + a_V f_{V\,\text{mean}}$$

$$a_V = \frac{a_e(f_s - f_e)}{f_{V\,\text{mean}} - f_s} \text{ and } a_e = \frac{a_V(f_{V\,\text{mean}} - f_s)}{f_s - f_e}$$

or, since $a_V = a_s - a_e$

$$a_e f_s - a_e f_e = a_s f_{V\,\text{mean}} - a_s f_s - a_e f_{V\,\text{mean}} + a_e f_s$$

$$a_s = \frac{a_e(f_{V\,\text{mean}} - f_e)}{f_{V\,\text{mean}} - f_s} \quad a_e = \frac{a_s(f_{V\,\text{mean}} - f_s)}{f_{V\,\text{mean}} - f_e} \quad . \quad (170)$$

$$C_V = \frac{a_s(f_s - f_e)(\alpha + f_{V\,\text{mean}}\beta)}{f_{V\,\text{mean}} - f_e}.$$

Example.—From 100 kg. of a vapour-mixture of methyl alcohol and water which contains 60% methyl alcohol, it is required to condense such a quantity that the residual vapour will contain 80%.

In this case $a_s = 60$, $f_s = 0{\cdot}666$, $f_e = 0{\cdot}250$, $f_{V_1} = 4{\cdot}811$, and $f_{V_2} = 1{\cdot}234$. If $f_{V\,\text{mean}}$ be taken as the arithmetic mean of the initial and final vapours,

$$f_{V\,\text{mean}} = \frac{4{\cdot}811 + 1{\cdot}234}{2} = 3{\cdot}0225;\ \alpha = 255;\ \beta = 550.$$

$$C_V = \frac{60(0{\cdot}666 - 0{\cdot}250)(255 + 3{\cdot}0225 \,.\, 550)}{3{\cdot}0225 - 0{\cdot}250} = 17{,}268 \text{ kg. cal.}$$

The total condensate :

$$a_{V\,\text{mean}} = \frac{17268}{1917} = 9{\cdot}008 \text{ kg.}$$

$$w_{V\,\text{mean}} = 27{\cdot}210 \text{ kg.}$$

36·218% of the original weight.

The residual vapour :

$$a_e = 51{\cdot}00 \text{ kg.}$$

$$w_e = 12{\cdot}79 \text{ kg.}$$

63·79% of the original weight.

On the other hand, Table 29, last column, shows that the residual vapour containing 80 per cent. alcohol obtained from a 60 per cent. mixture represents 61·3 per cent. (and not, as above, 63·79 per cent.) of the weight of the original vapour. This figure 61·3 is the result obtained by stepwise calculation.

In calculating Tables 22 and 29 it was assumed that a 60 per cent. vapour-mixture $a_s + w_s$ ($a_s = 1$ kg.) was condensed by stages in such a way that each residual vapour $a_e + w_e$ was 1 per cent. richer than the previous one, and that the ratio $f_{V\,\text{mean}}$ of each condensate $a_V + w_V$ was the arithmetic mean of the condensates of the two vapours differing in richness by 1 per cent. The fourth column gives the weight of alcohol in the residual vapour for each stage, the weight before each condensation being 1 kg.; the fifth column gives the weight of water in each residual vapour, and the sixth column the weight of the total residual vapour $a_e + w_e$. In the seventh column we find the weight of residual vapour for each stage expressed as a percentage of the weight of the original vapour; in the eighth column, the weight of residual vapour after completion of all the stages of condensation; and in the ninth column the weight of this vapour expressed as a percentage of the weight of the original vapour $a_s + w_s$. The data in the last column have been used to construct the curves given in Chart II, where the abscissæ give the percentages by weight of alcohol in the residual vapours, and the ordinates the percentages in the original vapours.

Table 22 and Chart II show that when a vapour-mixture of alcohol and water (60 per cent. wt.) is condensed in stages, the percentage of alcohol in the residual vapour increases approximately as the weight of the residual vapour diminishes.

19. SYNOPSIS OF THE CHIEF EQUATIONS REQUIRED IN CALCULATING THE DATA OF DISTILLING APPARATUS WHEN THE COMPOSITION OF THE MIXTURES IS GIVEN IN PERCENTAGES

The ratio of high-boiling to low-boiling component has been made the basis of all the foregoing considerations because it appeared advantageous to do so; but, obviously, the ratio of the weight of low-boiling component to that of the whole mixture $\frac{a}{a + w}$ could have been selected, in which case the proportion of

low-boiling component would be best expressed as a percentage-weight. If we represent percentage weights of a by p, and add a suffix to indicate the part of the apparatus where a is located, the principal equations that we have deduced assume the following forms :

In every case $a + w = 100$

If $a = p$ and $w = 100 - p$

$$f = \frac{100 - p}{p} = \frac{100}{p} - 1 \quad . \quad . \quad . \quad . \quad (171)$$

1. Latent Heat of Product :

$$C_e = a_e(\alpha + f_e\beta) = a_e\left(\alpha + \left(\frac{100}{p_e} - 1\right)\beta\right) \quad . \quad . \quad . \quad . \quad . \quad (172)$$

$$= p_e\alpha + (100 - p_e)\beta \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (173)$$

2. Latent Heat of Reflux :

(*a*) from reflux condenser :

$$C_V = \frac{a_e(f_s - f_e)(\alpha + f_V\beta)}{f_V - f_s} = \frac{a_e\left(\frac{1}{p_s} - \frac{1}{p_e}\right)\left(\alpha + \left(\frac{100}{p_V} - 1\right)\beta\right)}{\frac{1}{p_V} - \frac{1}{p_s}} \quad (174)$$

(*b*) from plates in the rectifying column :

$$C_R = \frac{a_e(f_d - f_e)(\alpha + f_R\beta)}{f_R - f_d} = \frac{a_e\left(\frac{1}{p_d} - \frac{1}{p_e}\right)\left(\alpha + \left(\frac{100}{p_R} - 1\right)\beta\right)}{\frac{1}{p_R} - \frac{1}{p_d}} \quad (175)$$

(*c*) into the boiling-vessel :

$$C_B = \frac{a_e(f_a - f_e)(\alpha + f_B\beta)}{f_B - f_a} = \frac{a_e\left(\frac{1}{p_a} - \frac{1}{p_e}\right)\left(\alpha + \left(\frac{100}{p_B} - 1\right)\beta\right)}{\frac{1}{p_B} - \frac{1}{p_a}} \quad (176)$$

(*d*) from plate M of continuous apparatus :

$$C_R = \frac{a_e(f_m - f_e)(\alpha + f_M\beta)}{f_M - f_m} = \frac{a_e\left(\frac{1}{p_m} - \frac{1}{p_e}\right)\left(\alpha + \left(\frac{100}{p_M} - 1\right)\beta\right)}{\frac{1}{p_M} - \frac{1}{p_m}} \quad (176a)$$

3. Heat-expenditure on plate M :

$$C_h = \frac{a_e(f - f_M)(\alpha + f_m\beta)}{f_M - f_m} = \frac{a_e\left(\frac{1}{p} - \frac{1}{p_M}\right)\left(\alpha + \left(\frac{100}{p_m} - 1\right)\beta\right)}{\frac{1}{p_M} - \frac{1}{p_m}} \quad (177)$$

4. Total heat of vapour rising from any plate in the rectifying column :

$$C_e + C_R = \frac{a_e(f_D - f_e)(\alpha + f_d\beta)}{f_D - f_d} = \frac{a_e\left(\frac{1}{p_D} - \frac{1}{p_e}\right)\left(\alpha + \left(\frac{100}{p_d} - 1\right)\beta\right)}{\frac{1}{p_D} - \frac{1}{p_d}} \quad . \quad (178)$$

5. Total heat removed from plate M of continuous apparatus :

$$C_e + C_N = \frac{a_e(f_M - f_e)(\alpha + f_m\beta)}{f_M - f_m} = \frac{a_e\left(\frac{1}{p_M} - \frac{1}{p_e}\right)\left(\alpha + \left(\frac{100}{p_m} - 1\right)\beta\right)}{\frac{1}{p_M} - \frac{1}{p_m}} \quad . \quad (179)$$

6. Total heat of vapour in boiling-column :

$$C_a = C_e + C_h + C_R = C_h + C_x = \frac{a_e(f - f_e)(\alpha + f_m\beta)}{f_M - f_m}$$
$$= \frac{a_e\left(\frac{1}{p} - \frac{1}{p_e}\right)\left(\alpha + \left(\frac{100}{p_m} - 1\right)\beta\right)}{\frac{1}{p_M} - \frac{1}{p_m}} \quad . \quad . \quad (180)$$

7. Total heat in boiling-column in relation to weight of high-boiling component :

$$C_a = C_e + C_h + C_R = C_h + C_x = \frac{(w - w_e)(\alpha + f_m\beta)}{f_M - f_m}$$
$$= \frac{(w - w_e)\left(\alpha + \left(\frac{100}{p_m} - 1\right)\beta\right)}{\frac{1}{p_M} - \frac{1}{p_m}} \quad . \quad . \quad (181)$$

8. Secondary heat required in section L of rectifying column :

$$C_z = \frac{a_e(f_m - f_e)(\alpha + f_m\beta)}{f_M - f_m} = \frac{a_e\left(\frac{1}{p_m} - \frac{1}{p_e}\right)\left(\alpha + \left(\frac{100}{p_m} - 1\right)\beta\right)}{\frac{1}{p_M} - \frac{1}{p_m}} \quad (182)$$

20. SEPARATION OF MIXTURES CONTAINING MORE THAN TWO COMPONENTS

It is not yet possible to give accurate mathematical expression to the changes which occur when mixtures containing more than two substances are separated in distilling apparatus: we do not know with sufficient accuracy the physical laws relating to the vaporisation of such mixtures, and the physical constants of the substances concerned have not yet all been determined. The proportions in which three or more liquids dissolve in one another, the composition of the vapour evolved from such mixtures, the latent heat of this vapour—particularly if the components interact chemically—none of these things is sufficiently well known to be of practical use; and the problems that have to be solved are rendered more complicated by the number of possibilities involved. Thus each of the component liquids may dissolve more or less, or not at all, in some or all of the other liquids; the mutual solubility may vary with the mixing proportions and with the temperature; and during separation the substances may change and give rise to new substances. The composition of vapours from substances that dissolve in one another is dissimilar to that of vapours from mutually insoluble substances; so here again complications arise and render an adequate mathematical treatment impossible.

For these reasons we must confine ourselves here to statements based on common knowledge and observation which indicate the general lines upon which apparatus to be used for such purposes must be designed. To give detailed information in this place would be beyond the scope of this work, and would, moreover, lead too far owing to the very varied nature of the substances that would have to be considered.

Mixtures, of which the components have different boiling-points and are miscible in all proportions, can usually be separated satisfactorily in apparatus of the periodic type; when these are so distilled, the liquid of lowest boiling-point appears first and the others follow in order. The efficiency of the separation depends, apart from the physical properties of the substances, upon the height of the columns and on the heat abstracted from the vapour in the reflux condenser. If one or more of the components is soluble only in the whole mixture, and the solubility decreases as soon as certain of the lower-boiling components have been

removed, then the conditions will approach those that obtain when two immiscible liquids are vaporised. In this case the common boiling-temperature is below that of the low-boiling component, and the composition of the vapour depends only on the pressure and the density of the individual vapours [1] (of the components) at the common temperature.

In such circumstances (*i.e.*, when during periodic rectification certain components become insoluble) the low-boiling substances will distil over in order of their volatility until the impoverished residue can hardly retain in solution the difficultly soluble substances. Then the latter usually begin to vaporise abundantly, and, accompanied by the other vapours, rise so high in the column that it becomes filled with low-grade mixtures. As this proceeds, the vapours evolved cease to remain consistently richer in low-boiling component, and may contain a large proportion of high-boiling material, provided that its pressure and density are greater than those of the other substances at the common temperature. This occurs, for example, when mixtures of water and amyl alcohol are distilled.[2]

When a mixture of several insoluble substances traverses the column of an *apparatus for continuous distillation*, it is resolved into two fractions only, one of which is a nearly pure component, and the other is residual mixture. The last-named can then be passed into a second column again to be resolved into two parts, and this process can, at any rate theoretically, be repeated at will until the last column delivers the two final fractions in a pure state. Thus two components are delivered by the last column, but only one by each of the previous columns. In this way every individual substance that is liberated in a column can leave it as vapour at the top, whilst the others flow from the base of it as a single liquid, which when passed into a new column will again

[1] E. Hausbrand, "Verdampfen, Kondensieren, Kühlen," 6th edition; C. von Rechenberg, "Theorie der Gewinnung und Trennung der ätherischen Oele durch Destillation" (Theory of the Production and Separation of Ethereal Oils by Distillation).

[2] E. Duclaux, *Ann. Chim. Phys.*, 1876, (5), 7, 264; I. Pierre and E. Puchot, *ibid.*, 1872, **26**, 145; *Compt. rend.*, 1871, **73**, 599, 778; F. Dolezalek, *Z. physikal. Chem.*, 1908, **64**, 727; D. Konowalow, *Ann. Physik (Wiedemann)*, 1881, **14**, 49, 219; Plücker, *Ann. Physik (Poggendorff)*, 1854, **92**, 193; R. A. Lehfeldt, *Phil. Mag.*, 1895, **40**, 397; 1898, **46**, 42; C. E. Linebarger, *J. Amer. Chem. Soc.*, 1895, **17**, 615; Jan v. Zawidski, *Z. physikal. Chem.*, 1900, **35**, 129; J. P. Künen, "Theorie der Verdampfung von Gemischteilen" (Theory of the Vaporisation of the Components of a Mixture), 1910.

part with a single component in the form of vapour. It is, however, possible to effect the separation of the highest-boiling component at the base of each column, from which it is run off in an almost pure state, and to allow the residual components to leave the top of each column as vapour, this being again passed into another column to be deprived of its highest-boiling component. The choice between these two methods must depend upon the physical properties of the substances concerned. If the substances, and their behaviour in admixture, are sufficiently well-known in respect of vapour-composition, temperature, latent and specific heats, the data for the columns, reflux condenser, and cooler can be calculated by means of the equations and formulæ already given; for if reasonably applied, the considerations previously advanced will be applicable in all these cases. To effect as perfect a separation as possible, each of the columns, whether these are placed alongside or above one another, must be provided with a lower element for the vaporisation, an upper element for the concentration, and, above this, a reflux condenser. Any special lay-out that is adopted must be modelled upon this simple pattern.

If a liquid mixture contains, in addition to perfectly soluble, also less soluble or even almost insoluble high-boiling components, complications at once ensue. It may happen that as the mixture in the boiling-vessel is deprived of low-boiling components, other components may thereby become almost insoluble, and therefore behave as insoluble liquids in regard to evolution of vapour. Vapours from this source will rise in abundance, together with other vapours, into the rectifying column, if they possess the necessary pressures and densities. In the rectifying column, the high-boiling matter which was insoluble below will dissolve easily in the enriched vapours near the top; but this redissolved matter will not play any important part in the vapour-mixtures that are formed in this column, because little or no vapour of it will be evolved from the liquids on the plates, where the low-boiling matter is in great excess. Cut off in this way both from the lower and the upper exit, the high-boiling vapours will accumulate in certain parts of the column, until they form an important proportion of the liquid mixtures. These mixtures will eventually yield a vapour and a liquid containing substances of high boiling-point which will force an exit, mix with the pure distillates and contaminate them.

The substances that are insoluble in the lower part but soluble in the upper part of the column must be prevented from accumulating in harmful proportions. Therefore a certain amount of the liquid must be drawn off, either continuously or at fixed intervals, from the right place in the column; and the insoluble material must be separated from it, so that the rest may be returned to the column. This procedure presupposes that only a small fraction of the liquids on certain plates has to be removed in order to eliminate the harmful material; otherwise it would be economically impracticable.

Economy in steam-consumption and the absence of subsidiary products that need working up are often claimed as the advantages of the continuous method of separation for mixtures containing many components. These advantages, however, do not always exist because, owing to the need of repeated condensation for reflux formation, such apparatus often consumes a considerable amount of heat; and well-constructed periodic apparatus does not always yield a large quantity of residual products. If, however, the mixture is not too complex, and if each constituent has not to be separated in a pure state, apparatus of the continuous type often serves very well for the simultaneous fractionation of high-grade mixtures.

21. POINTS CONCERNING THE CONSTRUCTION OF DISTILLING APPARATUS

But little can be said here about details of construction: owing to the widely differing nature of the substances that are separated by fractional distillation, and to the very diverse requirements of the industry, only an exhaustive treatment would be adequate; and that is not our intention. It sometimes happens that the same object can be achieved in different ways. The essential requirements of distilling apparatus in general are somewhat as follows.

In all apparatus the liquids must be afforded ample scope for circulation in order that clogging or stoppage may be avoided; the channels for circulation must be so disposed that the liquids traverse them in the ways desired. To avoid mutual hindrance, areas of cross-sections must be sufficiently large at the places where liquids and vapours come into contact. If a vapour has to penetrate a liquid, their points of contact must be as many

as possible; interaction takes place only at the interfaces, and these increase in area with the degree of comminution of the phases. The flow of materials must not be too rapid, but cross-sectional areas must be adequate. It is false economy to make an apparatus too constricted; and the aim should be to prevent liquid being carried up with the ascending vapours. This can be achieved by good construction. The efficiency of a column is impaired if drops of liquid penetrate into the upper parts of a column, and in our calculations we have assumed that this does not occur. The liquid should flow down from plate to plate only by the routes prescribed, not in unknown quantities through leaks or casual openings.

The quantity of mixture in the boiling-vessel of a periodic apparatus should be properly adjusted to the hourly yield. During distillation the content of low-boiling component diminishes to zero, but the weight and composition of the distillate remain practically constant. It is found that, on the average, the strength of the content of a boiling-vessel, calculated on 100 kg. of products, remains the same, whether that content be small, lasting only 10–24 hours, or large, lasting for 24–48 hours. Chart IV, and the small table below, show that the composition of the content of the boiling-vessel is always proportional to the weight of the material distilled over. The figures refer to a 50 per cent. alcohol–water mixture, to initial charges of 5000 and 10,000 kg. of mixture, and to an hourly yield of 150·65 kg. of 94·61 per cent. spirit (= 100 kg. alcohol).

Period of Distillation (hours):	0	6	12	18	21	24
Contents of Boiling-vessel: Alcohol (kg.):	2500	1900	1300	700	400	100
Contents of Boiling-vessel: Water (kg.):	2500	2466	2433	2393	2381	2364
	5000	4366	3733	3093	2781	2464
Per cent.:	50	43·5	34·84	22·61	14·38	4·05
Contents of Boiling-vessel: Alcohol (kg.):	5000	4400	3800	3200	2900	2500
Contents of Boiling-vessel: Water (kg.):	5000	4966	4932	4898	4883	4864
	10,000	9366	8732	8098	7783	7464
Per cent.:	50	46·72	43·51	39·53	37·02	34·81
Period of Distillation (hours):	30	36	42	48	50	
Contents of Boiling-vessel: Alcohol (kg.):	2000	1400	880	200	—	
Contents of Boiling-vessel: Water (kg.):	4830	4793	4759	4726	4714·7	
	6883	6193	5639	4926		
Per cent.:	29·28	22·60	14·32	4·22	0	

We gather from these data that consumption of heat and purity of product are independent of the relationship between

the content of the boiling-vessel and the hourly yield. Nevertheless, big charges are preferable to small, if only because they give better yields of pure distillate, other things being equal. This is undoubtedly connected with the fact that in practice two substances have not only to be separated from one another, but also from associated impurities. Since the impurities have not the same boiling-temperatures as the components, it is possible by skilful operation to accumulate them at the beginning and end of the distillation, and so to remove them unmixed. Hence when pure products are desired, it is better to use big charges.

PART II

In this Part the methods given in Part I for calculating the data of continuous separation are illustrated by detailed calculations relating to the separation of eleven different pairs of substances.

22. ETHYL ALCOHOL AND WATER

A. Physical Properties

We shall now apply the explanations and equations given in Part I to the calculation of mixtures of ethyl alcohol and water, and by discussing these mixtures in considerable detail we shall be able to explain some points which the previous treatment by bare formulæ may have left obscure.

Unless otherwise stated, the term "percentage" will signify percentage by weight, but as percentages by volume will also be used, we include, in Table 38, a conversion table taken from Märcker's "Handbuch der Spiritusfabrikation" (Handbook of Spirit Manufacture).

The following table of specific gravities of alcohol–water mixtures is due to Mendeléef.[1]

Alcohol.							
% wt.	Sp. gr.	% wt.	Sp. gr.	% wt.	Sp. gr.	% wt.	Sp. gr.
100	0·7936	75	0·8601	50	0·9179	25	0·9644
95	0·8086	70	0·8719	45	0·9287	20	0·9707
90	0·8225	65	0·8838	40	0·9389	15	0·9768
85	0·8354	60	0·8953	35	0·9484	10	0·9831
80	0·8479	55	0·9067	30	0·9570	5	0·9904

Regnault found the specific heat (σ) of pure ethyl alcohol to be 0·54754 at 0°, and 0·76938 at 80° C. The specific heat of the vapour, according to E. Wiedemann, is 0·4512 between 217° and 101°, and 0·4557 between 223° and 114°.

Schüller[2] observed that the specific heat of mixtures of ethyl alcohol and water is often greater than the value calculated from the equation $\sigma_m = \frac{\sigma_1 p_1 + \sigma_2 p_2}{p_1 + p_2}$, and his results have been con-

[1] D. Mendeléef, *J. Chem. Soc.*, 1887, **51**, 778; *Ann. Physik* (*Poggendorff*), 1869, **138**, 277, 279. W. Fresenius and L. Grünhut, *Z. anal. Chem.*, 1912, **51**, 123 (interpolations in Mendeléef's table).

[2] J. H. Schüller, *Ann. Physik* (*Poggendorff*), 1871, **5**, 116, 192; also Wiedemann's "Handbuch der Physik."

firmed by others. The specific heats of various mixtures are given in the following table, compiled by the author, where Schüller's figures appear in heavy type :

Alcohol.

% wt.	Sp. ht.	% wt.	Sp. ht.	% wt.	Sp. ht.	% wt.	Sp. ht.
	σ		σ		σ		σ
85	0·7100	60	0·893	44·35	**0·9610**	20	1·0400
83	0·7168	58·17	**0·8590**	40	1·0070	14·9	**1·0391**
80	0·739	55	0·8700	35·33	**1·0076**	10	1·0250
75	0·767	54·09	**0·8826**	30	1·0200	5	1·0110
73·9	0·777	50	0·9030	28·56	**1·0354**		
70	0·791	49·46	0·9163	25	1·0366		
65	0·890	45	0·9400	22·56	**1·0436**		

The latent heat of vaporisation (α) of pure alcohol was found to be 201·5 by Regnault, 214 by Brix, and 208 by Deprez. G. Zeuner [1] evaluated the latent heat at different temperatures as follows :

Temp. °C.	Latent heat.	Temp. °C.	Latent heat.
0	236·50	60	227·63
10	238·81	70	220·62
20	240·58	80	213·09
30	245·51	90	206·03
40	238·29	100	199·12
50	233·79		

Selecting a value for the latent heat of alcohol, we can calculate the latent heat of vapour-mixtures of alcohol and water (as was done in Table 2) if we assume that the latent heat of a vapour mixture is the sum of the values for the component vapours. In Part I it was stated that according to D. Tyrer this assumption is probably justifiable for non-reacting vapours, but may be incorrect for vapours that interact chemically, like those of alcohol and water. In the complete absence of experimental evidence, this assumption will also be made here, and it is hoped that no great error will be involved thereby. For this hope there is some justification. It may be that the sum of the latent heats of the component

[1] G. Zeuner, "Grundzüge der mechanischen Wärmetheorie" (Outlines of the Mechanical Theory of Heat).

vapours, which are valid for the common temperature lying between 79° and 100°, represents the most acceptable value for the latent heat of the mixture, in which case this value would be variable. We shall, however, assume that the latent heats of the component vapours remain constant, that of alcohol (α) being 205, and that of water (β) being 544 units, because otherwise the already somewhat involved calculations would become even more complicated and difficult to grasp. The comparative effects of considering and of neglecting the variations in the values of α and β with changing temperature may be seen from the following table:

Alcohol-content, per cent.	5	25	50	75	80
B[illegible] °C.	99·2	97	91	81	79
[illegible] the corresponding values of:					
α	199	202	207	214	212
β	536	535	542·8	551	550
From which follow the latent heats of the vapour mixture $a\alpha + w\beta$.	519	452	375	298	229
If, however, α and β are kept constant at 205 and 544, respectively, the latent heats of the vapour mixtures become	527	459	375	290	222

In view of the fact that the values found by different investigators for the latent heat of pure alcohol vary from 201·5 to 214, the above differences do not appear to be sufficiently great to invalidate our method of calculation.

Pure ethyl alcohol boils at 78° C.; the boiling-temperatures of its admixtures with water are given in Table 3.

The composition of the vapour evolved from alcohol–water mixtures has been investigated from time to time by various experimenters, but their observations are discordant. Some of their results are brought together in Table 2 and in Chart III. In the latter the abscissæ give the alcohol-content of the liquid, and the ordinates that of the vapour, both being expressed in percentages by weight. Experimental determinations have been made by the following: Gröning (the earliest), Blacher and Raschewski,[1] and Margules.[2] Lord Rayleigh[3] has recorded a few observations, H. Bergström,[4] of Stockholm, has recently published a fairly detailed table of results, which agree well with

[1] Prof. C. Blach[illegible] ommunication.
[2] M. Ma[illegible] . [illegible] . *Wiss. Wien*, 1895, **104** II, 1243.
[3] [illegible] . *Phil. Mag.*, 1902, (6), **4**, 521.
[4] Hilding Bergström, *Jern-Kontorets Annaler, Bihang.*

those of Blacher and Rayleigh; and lastly there is the observation communicated by Sorel.[1]

The second, third, and fourth curves for alcohol–water mixtures given in Chart III do not differ appreciably, but the first and fifth, due to Gröning and Sorel, respectively, differ markedly from the others for the temperature-range 20–70° C.

In the first two editions of this work Gröning's figures were made the basis of the calculations, and in the third edition Sorel's results were used. In the present edition Bergström's table has been selected, because his values agree almost exactly with those of Blacher, Rayleigh, and Margules, and, as the author has found, they accord best with practical experience. Sorel's curve appears to be the least accurate of all.[2]

Moreover, Lord Rayleigh's observation, confirmed by Bergström, that 95·5 per cent. (wt.) spirit gives a vapour with a lower alcohol-content, viz., 94·45 per cent., appears to indicate that Sorel's curve, which extends up to 100 per cent., is not in accordance with fact.[3, 4] Lord Rayleigh's observation is in agree-

[1] E. Sorel, "Distillation et rectification industrielle" (Industrial Distillation and Rectification), 1899.

[2] See also W. A. Noyes and R. R. Warfel, *J. Amer. Chem. Soc.*, 1901, **23**, 463, and J. P. Künen's "Theorie der Verdampfung und Verflüssigung von Gemischen" (Theory of the Vaporisation and Condensation of Mixtures), 1906, p. 114.

[3] S. Young (*J. Chem. Soc.*, 1902, **81**, 719) found the lowest boiling-point, 77·99° C. with a 95·57% mixture, Le Bel (*Compt. rend.*, 1879, **88**, 912) with a 95% (wt.) mixture, C. E. Linebarger (*Chem. News*, 1894, **70**, 52) with a 94·5% (wt.) mixture. Mixtures containing 97·59 and 97·778% (wt.) alcohol had the same boiling-point, 78·3° C.

[4] H. Masing, St. Petersburg, *Chem. Z.*, 1908, **32**, No. 63, 745. Experiments on the alcohol-content of the vapours evolved under reduced pressure from liquid mixtures of alcohol and water. From 1000 c.c. of mixture, 40 c.c. were vaporised in each case. All percentages given are percentages by weight.

Original Mixture.	Alcohol-content of Vapour.			
	760 mm. press.	400 mm. press.	220 mm. press.	40 mm. press.
%wt.	%	%	%	%
33·36	71·85	72·56	73·39	75·26
52·14	75·91	76·38	76·87	78·18
73·50	83·00	—	—	84·13
85·66	88·00	88·26	88·53	89·06
88·26	89·81	—	—	90·70
90·98	91·68	91·89	92·00	92·39
93·83	94·04	—	—	94·57
96·82	96·73	—	—	97·05

ment with the practical experience that rectification should be stopped when the alcohol-content reaches 95·35 per cent.

In Table 2, columns 3 and 5, will be found the values of the ratios $\frac{w}{a} = f$ and $\frac{w_d}{a_d} = f_d$, and in columns 6 and 7 the calculated values of the fractions $\frac{\alpha + f\beta}{f - f_d}$ and $\frac{\alpha + f_d\beta}{f - f_d}$, which will be frequently required in subsequent calculations.

The values given by Gröning, Margules, Blacher, Rayleigh, and Haywood for the composition of the vapour phase are given in Table 2 of the third edition of this work.

B. Heat-Consumption in Apparatus for the Periodic Rectification of Alcohol

We have already learnt that in order to produce a high-grade mixture of alcohol and water vapours $a_e + w_e$ (of ratio $\frac{w_e}{a_e} = f_e$) from a vapour-mixture of ratio $\frac{w_d}{a_d} = f_d$, a definite quantity of heat $C_V = C_R = C_B$ must be abstracted from the vapour in the reflux condenser, and the liquid condensate so formed must be returned to the column. We have seen that

$$C_B = \frac{a_e(f_a - f_e)(\alpha + f_B\beta)}{f_B - f_a} \quad . \quad . \quad . \quad . \quad (189)$$

We also learnt that C_B attains the theoretically lowest limit when the reflux from the lowest plate f_B has the same composition as the liquid in the boiling-vessel f_A from which the original vapour f_a was evolved. In practice this limit is unattainable; if it were attainable, the composition of the material on the lowest plate and that on all the higher plates would be the same, and consequently the concentration would make no progress. Therefore, more heat, and often much more heat, than is theoretically necessary must be withdrawn from the vapour in the reflux condenser; but the more closely f_B approaches f_A, the smaller is the amount of heat C_V required for the reflux.

Example.—It is required to produce 1 kg. of alcohol (a) in the form of 94·61% wt. spirit ($f_e = 0·057$) from a liquid in the boiling-vessel which contains 10% alcohol ($f_A = 9·00$) and evolves a vapour containing 51·6% ($f_a = 0·938$).

If the reflux into the boiling-vessel contains

	10%	20%	30% of alcohol
$f_B =$	9·00	4·0	2·333

and the corresponding amounts of reflux-heat required are

$$C_B = \frac{1(0{\cdot}938 - 0{\cdot}057)\,(205 + 9{\cdot}00\,.\,544)}{9{\cdot}00 - 1} = 561{\cdot}75 \text{ kg. cal.}$$

$$C_B = \frac{1(0{\cdot}938 - 0{\cdot}057)(205 + 4\,.\,544)}{4{\cdot}0 - 1} = 700{\cdot}0 \text{ kg. cal.}$$

$$C_B = \frac{1(0{\cdot}938 - 0{\cdot}057)\,(205 + 2{\cdot}333\,.\,544)}{2{\cdot}333 - 1} = 974{\cdot}3 \text{ kg. cal.}$$

We thus see that the amount of heat required for the reflux increases considerably with the amount of alcohol in it.

Table 11, calculated with the aid of equation (190), and Chart V give a general view of the smallest amounts of heat theoretically required to produce 1 kg. of alcohol as spirit of 85·76–92·37–94·61 per cent. by weight from a liquid containing from 93 to 0·5 per cent. by weight. In the Chart, the abscissæ give the alcohol-contents of the vapours from the original mixtures when distillation begins; the point of intersection of any ordinate with the curve indicates on the vertical axis the smallest number of heat-units required to provide 1 kg. of alcohol as spirit having the strength given on the curve.

Both Table and Chart show that, in general, the heat required for the reflux C_R in the rectifying column increases with diminishing strength of the original liquid; that when the latter is low (6 per cent. or less), the reflux heat is nearly independent of the strength of the product to be won; but that high-grade spirit always requires a large heat-consumption, even if the original liquid be fairly strong.

The fluctuations in the amount of reflux heat required are especially noticeable. The reflux-heat requirement does not fall off continuously as the alcohol-content of the original liquid declines, but only until a content of about 36 per cent. (for the liquid, 73·1 per cent. for the vapour) is reached; it then increases very considerably, at any rate when a very rich product is desired. The cause of this lies in the nature of alcohol–water mixtures, for like fluctuations were obtained when, in order to find the reason of this phenomenon, similar calculations were made with the data given by other investigators. Calculations relating to mixtures of other substances also led to the same result.

In using Table 11 for calculating the data of apparatus, the

highest value of C_R must be taken as basis when the alcohol-content of the original liquid lies between two consecutive values given in the table. In practice the amount of heat required will always be somewhat greater than the theoretically smallest amount given in Table 11.

C. The Number of Plates Needed in the Columns

When it is realised that a definite product can be obtained from a definite mixture by abstraction in the reflux condenser of rather more than the theoretical minimum of heat, and by repeated vaporisation in a column, it will be readily understood from previous considerations that progressive concentration from plate to plate will be greater the larger is the amount of high-grade reflux that flows down the column. The alcohol-content of the reflux increases with the amount of reflux (relatively to the amount of distillate), and one would naturally expect that fewer plates would be required if, for a given yield, the amount of reflux (and reflux heat) were increased. But the question as to how many plates are required in any given case has yet to be answered.

Now this answer cannot be obtained by the use of any single equation, because we do not yet possess a suitable mathematical expression connecting the compositions of the liquid and vapour phases. So long as this expression is lacking, the progress of vapour-concentration from plate to plate must be calculated for each separate case, consideration being given to the composition of the original liquid $a + w$, the desired product $a_e + w_e$, and the reflux heat C_R required to produce it. It is, however, quite easy to decide upon the number of plates to be used in any particular instance if we have before us the data derived from the study of a large number of special cases.

Table 12 contains a number of such data; it gives the alcohol-contents of the liquid and vapour on each plate of a rectifying column in which alcohol vapour of varying concentrations is being produced by the expenditure of varying amounts of reflux heat. This table shows that the number of plates required depends upon the alcohol-content of the original mixture: that the heat required increases as that content decreases; and that if the heat-expenditure is restricted to the theoretical

minimum, the number of plates required soon becomes excessive. Further, the heat-expenditure in apparatus for periodic distillation does not remain constant, but increases as the mixture in the boiling-vessel becomes poorer. With a constant hourly output the heat-requirement gradually increases; with a constant heat-expenditure, the hourly output diminishes. The use of many plates lowers the cost of production.

To calculate the dimensions of a column, we may start either from the boiling-vessel and proceed upwards, or from the reflux condenser and go downwards. The latter plan appears the better because it enables the product to be considered first, and on this account we shall use it in our calculations. An example will now be given to show the precise method of calculation. The assumption will be made that the composition of the reflux from the reflux condenser has the same relation to the composition of the product as the composition of the original mixture has to that of the vapour rising from it. Two columns producing a rather weak spirit have been selected, because when these are used the progressive decrease in alcohol-content, even at the top, is more pronounced than when a very high-grade product is aimed at.

Example.—It is required to produce 11·66 kg. of 85·76% (wt.) spirit (90% vol.), for which $a_e = 10$ kg. alcohol and $w_e = 1{\cdot}66$ kg. water. The amount of heat to be abstracted from the vapour in the reflux condenser of the first column is 5000 kg. cal., and from the vapour of the second column 10,000 kg. cal.

The reflux-heat requirements are:	$C_R = 5000 : C_R = 10{,}000.$
In each case:	
the product weighs	$a_e = 10$ kg.
	$w_e = 1{\cdot}66$ kg.
its ratio is	$f_e = 0{\cdot}166.$
Hence the reflux ratio is:	$f_V = 0{\cdot}2422$ (or 80·5%).

The weights of alcohol and water in the reflux are given by the equation:

$$C_V = a_V\,(\alpha + f_V\beta) = a_V\,(205 + 0{\cdot}2422\,.\,544) = 5000 \text{ or } 10{,}000 \text{ kg. cal.}$$

from which

$$a_V = \frac{5000}{336{\cdot}5} = 14{\cdot}88 \text{ kg.} \qquad a_V = \frac{10{,}000}{336{\cdot}5} = 29{\cdot}76 \text{ kg.}$$

$$w_V = a_V\,.\,f_V = 14{\cdot}88\,.\,0{\cdot}2422 = 3{\cdot}60 \text{ kg.} \qquad w_V = 29{\cdot}76\,.\,0{\cdot}2422 = 7{\cdot}21 \text{ kg.}$$

The weight of vapour leaving the column is the sum of the weights of the reflux and the product:

$$a_s = 14{\cdot}88 + 10 = 24{\cdot}88 \text{ kg.} \qquad a_s = 29{\cdot}76 + 10 = 39{\cdot}76 \text{ kg.}$$

$$w_s = 3{\cdot}60 + 1{\cdot}67 = 5{\cdot}27 \text{ kg.} \qquad w_s = 7{\cdot}21 + 1{\cdot}67 = 8{\cdot}88 \text{ kg.}$$

The ratio of this vapour is :

$$\frac{w_s}{a_s} = f_s = \frac{5{\cdot}27}{24{\cdot}88} = 0{\cdot}2118 \text{ (}i.e.\text{, } 82{\cdot}55\%\text{)}. \quad f_s = \frac{8{\cdot}88}{39{\cdot}76} = 0{\cdot}2228 \text{ (}i.e.\text{, } 81{\cdot}8\%\text{)}.$$

The vapour f_s comes from the liquid on the top plate of the column; according to Table 2, the ratio of the liquid is :

$$f_S = 0{\cdot}3793 \ (72{\cdot}5\%). \qquad f_S = 0{\cdot}423 \ (70{\cdot}25\%).$$

The reflux from the top plate is identical with this liquid. Its weight follows from the equation :

$$C_R = a_R(\alpha + f_R\beta)$$

$$a_R(205 + 0{\cdot}3793 \,.\, 544) = 5000 \text{ kg. cal.} \qquad a_R(205 + 0{\cdot}423 \,.\, 544) = 10{,}000 \text{ kg. cal.}$$

$$a_R = \frac{5000}{411} = 12{\cdot}165 \text{ kg.} \qquad a_R = \frac{10{,}000}{435} = 22{\cdot}98 \text{ kg.}$$

$$w_R = a_R f_R = 12{\cdot}165 \,.\, 0{\cdot}379 = 4{\cdot}59 \text{ kg.} \qquad w_R = 22{\cdot}98 \,.\, 0{\cdot}423 = 9{\cdot}70 \text{ kg.}$$

The vapour from the second plate (from the top) represents the sum of the reflux from it and the product

$$a_d = 12{\cdot}165 + 10 = 22{\cdot}165 \text{ kg.} \qquad a_d = 22{\cdot}98 + 10 = 32{\cdot}98 \text{ kg.}$$

$$w_d = 4{\cdot}59 + 1{\cdot}67 = 6{\cdot}26 \text{ kg.} \qquad w_d = 9{\cdot}70 + 1{\cdot}67 = 11{\cdot}37 \text{ kg.}$$

The ratio of this vapour is :

$$\frac{w_d}{a_d} = f_d = \frac{6{\cdot}26}{22{\cdot}16} = 0{\cdot}2825 \ (78{\cdot}0\%). \qquad \frac{w_d}{a_d} = f_d = \frac{11{\cdot}37}{32{\cdot}98} = 0{\cdot}345 \ (74{\cdot}25\%).$$

The vapour f_d is produced from the liquid on the second plate, whose ratio is given in Table 2 :

$$f_D = 0{\cdot}7857 \ (56\%) \qquad f_D = 1{\cdot}429 \ (41\%).$$

The reflux from the second plate is identical with this liquid. Its weight is given by the equation :

$$C_R = a_R = (\alpha + f_R\beta)$$

$$a_R(205 + 0{\cdot}7857 \,.\, 544) = 5000 \text{ kg. cal.} \qquad a_R(205 + 1{\cdot}429 \,.\, 544) = 18{,}000 \text{ kg. cal.}$$

$$a_R = \frac{5000}{632} = 7{\cdot}91 \text{ kg.} \qquad a_R = \frac{10{,}000}{980} = 10{\cdot}20 \text{ kg.}$$

$$w_R = a_R f_R = 7{\cdot}91 \,.\, 0{\cdot}7857 = 6{\cdot}210 \qquad w_R = 10{\cdot}20 \,.\, 1{\cdot}429 = 14{\cdot}566 \text{ kg. cal.}$$

The vapour from the third plate (from the top) represents the sum of the reflux and the product, and so on.

This procedure is continued until the tenth plate in column 1 and the sixth plate in column 2 are reached, where the liquids contain 11·30 and 7·68% of alcohol, respectively. The calculation is now complete because with reflux-heat expenditures of 5000 and 10,000 kg. cal., respectively, no lower alcohol-content can be attained.

The curves in Chart VI were constructed from the data given in Tables 12, 13, and 14. From the horizontal axis is erected an ordinate corresponding to each plate, the top plate being marked 1, and the rest, up to 50, following in numerical order. Each ordinate gives the alcohol-content of the vapour which rises from the plate to which it refers, when the amount of reflux-heat inscribed on the curve is used to produce 10 kg. of alcohol as 90–96·5 per cent. (vol.) spirit. This graphic representation shows quite clearly that very few plates are

required to produce 85·75 per cent. (wt.) spirit, but that many more plates, and also more reflux-heat, are needed when a 94·6 per cent. (wt.) spirit is desired.

D. The Reflux Condenser

For the reasons given in Section 6, it is known that the composition of the condensate produced in the reflux condenser must lie between the compositions of the first and last drops that are formed in it; but it cannot be their arithmetic mean. The mean composition can be found fairly accurately only by the tedious method of calculation by stages, because the physical changes concerned are not yet sufficiently well known, and also because various external causes, whose effects cannot be foreseen, disturb the regularity of the process. In the preparation of very high-grade spirit, the composition of the reflux from the reflux condenser can never be in much doubt, because it must always approximate to that of the spirit. In apparatus here considered, the possible divergencies from our assumptions are practically insignificant. Only in apparatus, usually of the continuous type, for making weak spirit of 88–92 per cent. (vol.) does the concentration effected in the reflux condenser cause a noticeable increase in the alcohol-content of the spirit; and in this case it would be desirable, if possible, to make an exact predetermination of the composition of the reflux. However, in the absence of more knowledge, the choice of the arithmetic mean of the compositions of the first and last drops cannot involve any appreciable error.

Table 15 shows the concentrating action of the reflux condenser in the recovery of 10 kg. of alcohol as 85·76 per cent. (wt.) spirit when 5000 and 7000 kg. cal. are abstracted in it. Comparison with the figures given in Table 12 shows that the concentration effected by the reflux condenser is equal to that of four or three plates, according as the reflux heat C_R is 5000 or 7000 kg. cal.

The values of C_R given in the following table were calculated by inserting different values for f_s and for $f_{R\,\text{mean}}$ in the equation

$$C_V = \frac{a_e(f_s - f_e)(\alpha + f_{R\,\text{mean}}\beta)}{f_{R\,\text{mean}} - f_s},$$

f_e being equal to 0·2422.

Vapour in column.	f_s	f_R	f_{Rm}	C_R
%				kg. cal.
55	0·816	7·500	3·871	490
54	0·852	7·928	4·085	512
53	0·887	8·345	4·294	534
52	0·923	8·804	4·523	558
51	0·961	9·204	4·723	583
50	1·000	9·700	4·971	610
49	1·032	10·111	5·177	629
48	1·083	10·695	5·459	663
47	1·128	11·195	5·719	693
46	1·174	11·658	5·920	739
45	1·222	12·333	6·238	780

If $C_V = 5000$ kg. cal., the value of $f_{R\,\text{mean}}$ is 3·969 (see 80·5 per cent. $f_R = 0{\cdot}2422$ and 11·5 per cent. $f_R = 7{\cdot}6957$), and if $C_V = 7000$ kg. cal., $f_{R\,\text{mean}}$ is 5·793 (see 80·5 per cent. $f_R = 0{\cdot}2422$ and 8·1 per cent. $f_R = 11{\cdot}345$). In this way the value of f_s could be determined and the calculation of the column be made as usual. It must, however, not be forgotten that the choice of the arithmetic mean introduces an error which at present cannot be avoided.

E. Numerical Examples to show the Retardation caused by using Small Reflux Condensers between the Plates instead of a Single Reflux Condenser on top of the Column

Table 16 is inserted to show the disadvantage of replacing the single reflux condenser at the top of the column by a number of reflux condensers between the plates, of which the combined cooling effect is equal to that of the one (cf. Section 7, p. 28). This table gives the weight and alcohol-content of vapour and liquid on each plate in the two columns. The first column is provided at the top with a single reflux condenser capable of abstracting 10,000 kg. cal., and the second column with six reflux condensers disposed as follows: one above each of the plates numbered 9, 13, 15, 17, 19 that abstracts 1000 kg. cal., and one at the top that abstracts 5000 kg. cal. Each column has an output capacity of 10 kg. alcohol as 92·57 per cent. (wt.) spirit, and the lowest reflux from each contains 5·25 per cent. (wt.) of alcohol. Although the second column is cooled mainly at the top, the retardation caused by the intermediate cooling

is quite apparent. The values recorded in Table 16 were calculated in the manner shown in Sections 7 and 22 (C).

It will be readily understood, and may be easily demonstrated, that the heat lost by radiation from the heated columns involves a loss similar to that incurred by using a number of small reflux condensers.

Rectifying columns should always be provided with a single, superimposed, reflux condenser, and be protected by lagging against loss of heat.

F. Example to show that in Rectifying without Plates, *i.e.*, simply by Condensation in the Reflux Condenser, the Successive Condensates should be as small as possible

Table 17 shows that if from 100 kg. of a 50 per cent. alcohol–steam mixture, vapours containing 55, 60, 65, 70, 75, 80 per cent. are produced successively by six consecutive withdrawals of heat, the weight of the residual vapour containing 80 per cent. alcohol is 34·46 kg.; but if the heat is withdrawn in such large instalments that only two residual vapours, containing respectively 70 and 80 per cent. alcohol, are left, then the weight of the residual 80 per cent. vapour is only 17·73 kg. This example demonstrates that if vapour-mixtures of alcohol and water are to be rectified by fractional condensation with immediate separation of the condensates and without the use of plates, such condensation must be effected slowly and in small quantities. If this is done, the result is almost the same as that obtained when the vapour under condensation is carried away continuously from the condensate.

G. Apparatus for the Continuous Distillation of Alcohol

1. *The Boiling-column*

The function of a boiling- or wash-column is to separate (at its base) from a mixture most of the water and any suspended solids that may be present, in such a way that only small traces of alcohol are run off with the spent wash, and the alcohol-content of the liquid on plate M is as high as the circumstances allow. The heat required for this purpose is usually passed direct into the wash-column in the form of live steam, but is sometimes

supplied by means of heated coils or tubes which generate vapour from the spent wash and therefore do not increase the amount of water present.

The heat-consumption of boiling-columns for every 100 kg. of wash increases as the actual amount of alcohol increases, and also as the concentration of alcohol diminishes. The question therefore arises: How many heat-units C_a must be supplied to such a column in order to obtain almost pure water as spent liquor, and alcohol of predetermined strength for passing on to the rectifying column?

The answer to this question is furnished by reference to an earlier equation

$$C_a = \frac{(w - w_e)(\alpha + f_m\beta)}{f_M - f_m} \quad . \quad . \quad . \quad . \quad (190)$$

in which $w - w_e$ is the weight of water to be separated, and f_M, f_m are the ratios of the liquid and vapour on plate M; when the values of these are given, the heat-consumption of the wash-column is determined. The above equation was used for calculating Table 18, which gives the number of heat-units required to separate 100 kg. of water from mixtures containing from 85 down to 0·5 per cent. of alcohol. Here again we find that much more heat is needed to fractionate rich mixtures than poor mixtures.

Also, the last column of Table 2 gives the amount of heat required to separate 1 kg. of water from mixtures on plate M, the composition of which is given in columns 2 and 4. The values given in column 7 multiplied by the values of $(w - w_e)$ give the heat required to separate this weight of water from 100 kg. of wash.

Example.—Calculation of the heat required to separate 1 kg. water from mixtures on Plate M.

	Alcohol-content of boiling mixture on plate M		
	3%	10·1%	50%
Ratio f_M	32·33	9·0	1·0
	Alcohol-content of vapour from plate M		
	26·3%	51·6%	76·8%
Ratio f_m	2·802	0·938	0·3038
	Heat required to separate 1 kg. water		
	$\frac{1(205 + 2{\cdot}802 \,.\, 544)}{32{\cdot}33 - 2{\cdot}802}$	$\frac{1(205 + 0{\cdot}938 \,.\, 544)}{9 - 0{\cdot}938}$	$\frac{1(205 + 0{\cdot}3038 \,.\, 544)}{1 - 0{\cdot}3038}$
	$C_a = 58{\cdot}5$	87·6	531 kg. cal.

Exactly as for the rectifying column, the number of plates required in the wash-column must be determined separately in every case, for this number cannot be calculated by any one formula. The changes in weight and composition of the liquids and vapours must be followed from plate to plate, a definite expenditure of heat-quantities being assumed. For these calculations, Table 18 will be of service, as it gives, in column 2, the highest attainable alcohol-content of the vapour from the top plate when the heat-expenditure for 100 kg. of spent wash is that given in column 3. Equation (190) was used for calculating this table: 100 kg. was taken as the weight of spent wash $w - w_e$ and 0·01 per cent. as its alcohol-content: and for f_M and f_m the ratios of the various alcohol-mixtures on plate M were inserted.

The curves in Chart VII represent the heat-consumption of wash-columns for alcohol–water mixtures. The numbers of the plates are given on the horizontal axis; and the alcohol-contents of the vapours rising from plate M are given by the abscissæ of the points where the ordinates cut the curves.

Table 19 and Chart VII give the calculated results for a number of boiling-columns (wash-columns), namely, the percentage of alcohol in the vapour and liquid on every plate when the heat-expenditure varies from 5500 to 450,000 kg. cal. per 100 kg. of spent wash.

We learn that the number of plates required to secure a definite alcohol-content on the top plate diminishes as the heat-expenditure is increased, and that the highest attainable concentration is determined by that expenditure. The calculation can be started either from the bottom or from the top of the column, but the former method appears to be preferable, because in this case the alcohol-content of the spent wash can be chosen at will, whilst the highest attainable alcohol-content of the vapour at the top is already known (from Table 18) at the beginning of the calculation.

Example.—Let the heat-expenditure per 100 kg. of spent wash in two wash-columns be, respectively,

C_a = 10,000 kg. cal. 200,000 kg. cal.

In both cases:

Alcohol in spent wash	=	0·01%
Alcohol in vapour from spent wash	=	0·1%
Ratio of vapour f_a	=	1000

Weights of components in this vapour :

$C_a = a_a(205 + 1000 \,.\, 544) = 10{,}000$ kg. cal. $= 200{,}000$ kg. cal.

Alcohol $a_a = 0{\cdot}0184$ kg. $\qquad a_a = 0{\cdot}3676$ kg.

Water $w_a = 0{\cdot}0184 \,.\, 1000 = 18{\cdot}4$ kg. $\qquad w_a = 0{\cdot}3676 \,.\, 1000 = 367{\cdot}6$.

The reflux from the first (bottom) plate is the sum of the weight of this vapour + 100 kg. spent wash $(w - w_e)$

$a_R = 0{\cdot}0184$ kg. $\qquad a_R = 0{\cdot}3676$ kg.

$w_R = 118{\cdot}4$ kg. $\qquad w_R = 467{\cdot}6$ kg.

Its ratio :

$$f_R = \frac{w_R}{a_R} = \frac{118{\cdot}4}{0{\cdot}0184} = 6435 \qquad f_R = \frac{467{\cdot}6}{0{\cdot}3676} = 1272.$$

Alcohol-content of this reflux :

0·0156% $\qquad$ 0·079%.

Alcohol-content of vapour from bottom plate :

0·171% $\qquad$ 0·869%.

Its ratio f_d :

875 $\qquad$ 115.

Weights of components in this vapour :

$C_a = a_d(205 + 875 \,.\, 544) = 10{,}000$. $\qquad a_d(205 + 115 \,.\, 544) = 200{,}000$ kg. cal.

Alcohol $a_d = 0{\cdot}0210$ kg. $\qquad a_d = 3{\cdot}187$ kg.

Water $w_d = a_d \,.\, f_d = 0{\cdot}0210 \,.\, 875 = 18{\cdot}37$ kg. $\qquad w_d = 3{\cdot}187 \,.\, 115 = 366{\cdot}5$ kg.

The weight of reflux from the second plate is the sum of the weight of this vapour and 100 kg. spent wash $(w - w_e)$:

$a_R = 0{\cdot}0210$ kg. $\qquad a_R = 3{\cdot}187$ kg.

$w_R = 118{\cdot}37$ kg. $\qquad w_R = 466{\cdot}5$ kg.

Its ratio :

$$f_R = \frac{w_R}{a_R} = \frac{118{\cdot}37}{0{\cdot}0210} = 5637 \qquad f_R = \frac{466{\cdot}5}{3{\cdot}187} = 146{\cdot}3$$

(*i.e.*, 0·019%) $\qquad$ (*i.e.*, 0·68%).

Alcohol-content of vapour from the second plate :

0·20% $\qquad$ 7%

and so on.

The above method of treatment is of general applicability. We can now pass on to the determination of the heat-consumption and of the number of plates required in apparatus for the continuous separation of alcohol–water mixtures.

2. *The Rectifying Column is placed above the Boiling-column (Wash-column)*

It has been shown that under optimum conditions the composition of liquid and vapour on plate M (Fig. 2, p. 8) depends only on the alcohol-content of the wash and on the heat C_h

which must be applied to the wash in order to raise its temperature from t_v to its boiling-temperature t_m. The equation to be employed is

$$C_h = \frac{a_0(f - f_M)(\alpha + f_m\beta)}{f_M - f_m} \quad . \quad . \quad . \quad . \quad (191)$$

With the aid of this equation Table 20 has been calculated, and the values obtained are represented graphically in Chart VIII. In this way we see how the alcohol-content on plate M increases when the liquid on it is heated and brought to boiling-temperature by the vapours which reach it from below. Both Table and Chart show that the secondary heating produces a greater enrichment in solutions that were originally weak than in those that were originally strong.

The amount of secondary heat C_h which must be applied to the wash to raise its temperature to the boiling-point, is found from the difference between t_m, the boiling-temperature, and t_v, its temperature in the preheater. The latter can be fixed by adjusting the heating surface of the coils in the preheater, but it will always be a few degrees below the temperature of the vapour inside the coils (*i.e.*, about 78–85° C., the temperature of the vapour as it comes from the rectifying column).[1]

Accordingly the secondary heat needed is

$$C_h = (a + w)\sigma(t_m - t_v) \quad . \quad . \quad . \quad . \quad (192)$$

To what temperature should the wash be raised in the preheater in order that the apparatus may work with maximum economy?

The heat abstracted from the vapour in the reflux condenser can obviously be used to preheat the wash, and, if possible, the

[1] The required heating-surface in the preheater can be found as follows:—

The heat needed to raise $(a + w)$ kg. of wash, of sp. heat σ, from its initial temperature t up to t_v is:

$$C_v = (a + w)\sigma(t_v - t) \text{ heat units.}$$

If t_s is the temperature of the vapour from the rectifying column, and if $\frac{t + t_v}{2}$ be taken—somewhat inaccurately—as the mean temperature of the wash, then the mean temperature-difference $\theta_m = t_s - \frac{t_v + t}{2}$, and the required heating-surface is $F_v = \frac{C_v}{\theta_m k}$, where k is the coefficient of heat-transmission. (E. Hausbrand, "Verdampfen, Kondensieren und Kühlen," 1920).

two heat-quantities C_v and C_V should be made equal, but in practice this is seldom possible; and theoretically the two quantities are necessarily different. The wash can only take up a certain and limited amount of heat C_v, depending chiefly on the initial temperature t: the reflux heat C_V depends upon the alcohol-content of the wash and on that of the spirit produced. C_V may be greater than C_v, and usually must be so, in which case additional water-cooling is necessary. In actual practice it is found that the heat-requirement C_v suffices for the production of the reflux heat C_V when a 90–92 per cent. (vol.) spirit has to be produced from a wash containing up to 9 per cent. of alcohol, but if a 96·5 per cent. (vol.) spirit be required, C_v suffices only if the original wash contains up to about 3 per cent. Therefore C_v and C_V cannot always be equal, although if this is possible the apparatus may be arranged accordingly. In certain cases the heat required by the wash may be obtained from that set free during the cooling of the product.

Now $C_v + C_h$ represents the total heat required to raise the wash from t its initial temperature to t_m its boiling-temperature on plate M. This quantity of heat is known fairly accurately, being given by the equation

$$C_v + C_h = (a + w)\sigma(t_m - t) \quad . \quad . \quad . \quad (193)$$

and since the latent heat of the product C_e can always be easily found, being given by

$$C_e = a_e(\alpha + f_e\beta) = a_e(205 + f_e\,544) \quad . \quad . \quad . \quad (194)$$

it will be clear that the following equation gives the entire heat-requirement for the distillation conducted under optimum conditions

$$C_a = C_v + C_h + C_e = \frac{a_e(f - f_e)(\alpha + f_m\beta)}{f_M - f_m} \quad . \quad . \quad (195)$$

which we have already obtained in equation (99), except that C_v here takes the place of C_V.

Equation (195) can be used to find the composition of vapour and liquid on plate M, the conditions being the most favourable economically. Obviously, the heat required in the distillation cannot be less than the sum of the heat required to raise the liquid from t to t_m and the heat required to vaporise the product. Since the vapour in the reflux condenser is always at a lower temperature than the mixture boiling on plate M, a certain

amount of secondary heat C_h must always be applied to this plate, and consequently the liquid on it is always richer in alcohol than the original wash (Table 20, Chart VIII).

The alcohol-content of the liquid on plate M increases as C_h increases, and this is also true of the factor $\frac{\alpha + f_m\beta}{f_M - f_m}$ (*v.* Table 2, column 7, and corresponding tables for other mixtures).

From this it follows that the heat required for the distillation diminishes as the value of C_h decreases, *i.e.*, the temperature in the preheater t_v should be as high as possible. This is the answer to the question asked above.

Once the preheating-temperature t_v has been chosen (as high as possible), equation (192) can be used to calculate the value of C_h (which should be as small as possible), and equations (99) and (191) to calculate the values of f_M and f_m. The value of $C_v + C_h + C_e$ is obtained from equation (195), and C_e and C_h being known, that of $C_v(=C_V)$ follows.

In the above cases, where the total heat-consumption is the sum of the heat applied to the mixture and that required to vaporise the product, it is possible to start the calculation from $C_a = C_v + C_h + C_e$, the value of which is known from equation (195). The values of f_M and f_m are then deduced (after a few trials with the aid of Table 2), and by inserting these in equation (191) C_h is found, and then the preheating-temperature t_v. Finally, C_v is found by subtraction $(C_v + C_h + C_e - C_e - C_h)$. The following example will make this clear.

Example.—From 100 kg. of wash containing 10% alcohol ($a = 10$, $w = 90$ kg.) at a temperature $t = 20°$ C., it is required to make spirit of 85·76% wt. or 90% vol. ($f_e = 0{\cdot}166$). The wash is preheated to 70° in the reflux condenser, and its specific heat is 1·01.

$$C_v = 100 \,.\, 1{\cdot}01(70 - 20) = 5050 \text{ kg. cal.}$$

On plate M the wash boils at 90°, and therefore the heat to be supplied to it is

$$C_h = 100 \,.\, 1{\cdot}01(90 - 70) = 2020 \text{ kg. cal.}$$

After trial with the data in Table 2, it follows from equation (191) that

$$f_M = 7{\cdot}000 \text{ and } f_m = 0{\cdot}780$$

$$C_h = \frac{10(9 - 7)(205 + 0{\cdot}780 \,.\, 544)}{7{\cdot}00 - 0{\cdot}780} = 2022 \text{ kg. cal.}$$

i.e., the alcohol-content of the liquid on plate M is 12·5% and that of the vapour 56·15%.

The latent heat of the recovered spirit is

$$C_e = 10(205 + 0{\cdot}166 \,.\, 544) = 2953 \text{ kg. cal.}$$

The actual heat-consumption is therefore :

$$C_a = C_v + C_h + C_e = 5050 + 2020 + 2953 = 10{,}023 \text{ kg. cal.}$$

To find the total heat-consumption C_g, we should have to include one-half of the heat required to raise the temperature of the reflux from t_V to t_a (C_o and C_u) and the radiated heat (C_{st}).

[By inserting the above values of f_M and f_m in equation (73) we find that

$$C_R = \frac{a_e(f_m - f_e)(\alpha + f_M\beta)}{f_M - f_m} = 3961 \text{ kg. cal.},$$

i.e., the smallest amount of reflux heat theoretically required, $C_V = 3961$ kg. cal., is less than C_v, which is 5050 kg. cal. This means that the column can be shortened.]

[The value of C_R, the minimum reflux heat needed in the rectifying column, can also be derived from equation (68) :

$$C_a = C_R + C_h + C_e = \frac{a_e(f - f_e)(\alpha + f_m\beta)}{f_M - f_m}$$

If in this equation we insert the previously found values of the alcohol-contents on plate M, we obtain $C_a = C_R + C_h + C_e =$

$$\frac{10(9 - 0{\cdot}166)(205 + 0{\cdot}780 \,.\, 544)}{7{\cdot}00 - 0{\cdot}780} = 8938 \text{ kg. cal.}$$

and since $C_h + C_e = 2020 + 2953 = 4973$ kg. cal., we obtain by subtraction the value 3965 for the minimum heat-requirement of the reflux C_R, which agrees with that found from equation (73).]

* * * * * * *

The secondary heat required to raise the temperature of the reflux from the reflux condenser from t_V to t_m, the temperature on plate M, is $C_o = \frac{C_V}{c_V}\sigma_V(t_m - t_V)$, where σ_V is the specific heat and c_V the latent heat of the reflux. Now since the reflux changes in composition from plate to plate, we may assume, if somewhat inaccurately, that σ_V and c_V are the arithmetic means of the values that obtain at the top and bottom of the column; for the total amount of heat concerned is small, and otherwise the calculation would become exceedingly involved.

In a similar way, we may calculate the secondary heat required for the spent wash $w - w_e$, and the heat required to raise the temperature of the condensate on plate M, $a_h + w_h +$

$a_x + w_x$, from t_m to t_a, the temperature of the spent wash (= 102° C.). Therefore

$$C_u = \left\{\left(\frac{C_h + C_x}{c_{M\,\text{mean}}}\right)\sigma_{M\,\text{mean}} + (w - w_e)\right\}(t_a - t_m)$$

Example.—If the liquid on the top plate of the rectifying column be 85% wt. (*i.e.*, $f_V = 0{\cdot}167$), and that on plate M be 12·5% (*i.e.*, $f_M = 7{\cdot}091$), then the mean strength is $\frac{0{\cdot}167 + 7{\cdot}091}{2} = 3{\cdot}629$, *i.e.*, 21·5%.

The mean latent heat is

$$c_{V\,\text{mean}} = \frac{21{\cdot}5\,.\,205 + 78{\cdot}5\,.\,544}{100} = 471{\cdot}1 \text{ units.}$$

The specific heat $\sigma_V = 1{\cdot}04$; $t_m - t_V = 90{\cdot}2 - 80 = 10{\cdot}2°$ C.

Therefore, since $C_R = 5050$ kg. cal.

$$C_o = \frac{5050}{471{\cdot}1}\,.\,1{\cdot}04\,.\,10{\cdot}2 = 113{\cdot}8 \text{ kg. cal.}$$

The heat given out by the vapour condensing on plate M is $C_v + C_h + C_e = 5050 + 2020 + 2953 = 10{,}023$ kg. cal. The alcohol-content on plate M is 12·5 per cent., in the spent wash 0 per cent., a mean of 6·25 per cent., therefore the latent heat is

$$c_{M\,\text{mean}} = \frac{6{\cdot}25\,.\,205 + 93{\cdot}75\,.\,544}{100} = 512{\cdot}8.$$

The specific heat $\sigma_{M\,\text{mean}} = 1{\cdot}01$; $t_a - t_m = 102 - 90{\cdot}2° = 11{\cdot}8°$ C., $w = 90$ kg., $w_e = 1{\cdot}66$ kg., $w - w_e = 88{\cdot}34$ kg. Therefore the secondary heat required to heat the reflux in the boiling-column is

$$C_u = \left(\frac{10{,}023}{512{\cdot}8}\,.\,1{\cdot}01 + 88{\cdot}34\right)11{\cdot}8 = 1275{\cdot}3 \text{ kg. cal.}$$

The following quantities of heat are required, therefore, to produce 10 + 1·66 = 11·66 kg. of 85·76 per cent. (wt.) spirit :

Heat of the product	$C_e =$		2953 kg. cal.
Heat required on plate M	$C_h =$		2020 ,,
Reflux heat (preheat)	$C_v =$		5050 ,,
Secondary heat for reflux above	$C_o =$	113·8 kg. cal.	
,, ,, ,, below	$C_u =$	1275·0 ,,	
Heat lost by radiation	$C_{st} =$	175·0 ,,	
One half of $C_o + C_u + C_{st}$			782 ,,
		Total $C_g =$	10,805 kg. cal.

Calculated on 100 kg. of spent wash

$$C_g = \frac{10{,}805\,.\,100}{88{\cdot}54} = 12{,}231 \text{ kg. cal.}$$

$$[88{\cdot}54 = 100 - 11{\cdot}46].$$

On consulting Tables 12 and 19, we find that four plates are needed in the rectifying column and thirteen in the wash-column.

If we had to produce a spirit of 94·6 per cent. (wt.) instead of an 85·76 per cent. spirit from the same wash, we should have to use more heat for the reflux in the rectifying column, namely, the theoretically greatest amount given in Table 11, which is 807 kg. cal. for 1 kg. alcohol. The expenditure of such a small amount of heat would, however, necessitate the use of an excessive number of plates in the rectifying column; we must at least use the amount 12,000 kg. cal. for 10 kg. alcohol given in Table 14, and in this case forty plates would be required.

The following are the minimum heat-quantities required to produce 10 + 0·57 = 10·57 kg. of 94·6 per cent. (wt.) spirit:

$C_e = 10(205 + 0{\cdot}057 \,.\, 544)$	=	2360 kg. cal.
C_h	=	2020 ,,
C_V	=	12000 ,,
	Total	16,380 kg. cal.

To heat the reflux at the top, we require

$$C_o = \frac{12{,}000}{470} \,.\, 1{\cdot}04 \,.\, 10{\cdot}3 = 274 \text{ kg. cal.}$$

One-half of this = 137 kg. cal.

To heat the reflux below

$$C_u = \left(\frac{16{,}380}{513} \,.\, 1{\cdot}01 + 89{\cdot}43\right)(102 - 90)$$

$$= 1460 \text{ kg. cal.}$$

One-half of this = 730 ,,

Heat lost by radiation = 200 kg. cal.

One-half of this = 100 ,,

Total heat-requirement C_g = 17,347 kg. cal.

Calculated on 100 g. of spent wash

$$C_g = \frac{17{,}347 \,.\, 100}{89{\cdot}43} = 19{,}442 \text{ kg. cal.}$$

In this case Tables 12 and 19 show that forty plates are needed in the rectifying column and seven plates in the wash-column.

If for safety another 1000 kg. cal. is used for 100 kg. of wash, thirty-seven plates will suffice for the rectifying column and six for the wash-column.

3. *The Rectifying Column is placed alongside the Boiling-column (Wash-column)*

By placing the rectifying column alongside the wash-column, instead of above it, no change occurs in the composition of the liquid on plate M, *ceteris paribus*, for this composition depends only on the amount of secondary heat C_h applied, which can obviously be the same in both cases. The vapour leaving the boiling-column, and containing all the alcohol a that was in the wash, must have the same ratio f_m, and the alcohol-content of the liquid on plate M must also be the same; this is shown by equation (191):

$$C_h = \frac{a_e(f - f_M)(\alpha + f_m\beta)}{f_M - f_m}$$

The effective heat in the wash-column is also the same:

$$C_a = C_h + C_m = \frac{a_e(f - f_M)(\alpha + f_m\beta)}{f_M - f_m} + a_e(\alpha + f_m\beta)$$

$$\mathbf{C_a = \frac{a_e(f - f_m)(\alpha + f_m\beta)}{f_M - f_m}} \quad . \quad . \quad . \quad . \quad (196\,a)$$

Example.—If the wash, the product, and the secondary heat are the same as in the preceding example, *i.e.*, for 90% vol. spirit, $C_e = 2953$ and $C_h = 2020$, ; . on M contains 12·4%, $f_m = 0{\cdot}780$ and $C_m = 10(205 + 0{\cdot}780 \,.\, 544) = 6293$ kg. cal.

Therefore $C_h + C_m = 8313$ kg. cal.

The same result must, of course, follow from the following equation:

$$C_h + C_m = \frac{10(9 - 0{\cdot}780)(205 + 0{\cdot}780 \,.\, 544)}{7{\cdot}00 - 0{\cdot}780} = 8313 \text{ kg. cal.}$$

The weight of vapour leaving the wash-column is:

$$a = 10 \text{ kg.} \qquad w = 10 \times 0{\cdot}780 = 7{\cdot}80 \text{ kg.}$$

The exhausted liquor from the wash-column is

$$w - w_m = 90 - 7{\cdot}80 = 82{\cdot}20 \text{ kg.}$$

Secondary heat required for the reflux:

$$C_u = \left(\frac{8313}{572{\cdot}8} \,.\, 1{\cdot}01 + 82{\cdot}20\right)(102 - 90{\cdot}2) = 1143 \text{ kg. cal.}$$

Radiated heat $C_{st} = 150$ kg. cal.

The heat-requirement of the wash-column is therefore:

$$C_a = 8313 + \frac{1143 + 150}{2} = 8959 \text{ kg. cal.}$$

or, for 100 kg. of spent wash:

$$C_a = \frac{8959 \,.\, 100}{89{\cdot}2} = 10{,}044 \text{ kg. cal.}$$

Table 19 shows that this column must have seventeen plates.

The vapour rising from plate M ascends on to the lowest plate of the upper part of the adjacent rectifying column (*v.* Fig. 3); its composition is the same as, although its weight is less than, when it ascends into a superimposed rectifying column (Fig. 2). In order that this vapour may yield the same weight of the same product, the reflux heat must be the same in both cases, *i.e.*, $C_V = 5050$ kg. cal., and since the heat of the product and the secondary heat required for the reflux remain the same

$$C_e = 2953 \text{ and } C_e + C_R + \frac{C_o}{2} = 2953 + 5050 + \frac{114}{2} = 8060 \text{ kg. cal.}$$

We thus see that the data for the rectifying column are independent of the mode of arrangement; and this is also true for the preheater or reflux condenser. Since, however, the vapour from the wash-column conveys to the top plate L^1 of the lower part of the rectifying column the heat $C_m = 6293$ kg. cal., which does not suffice to form the reflux, this lower part of the column must supply the additional heat required

$$C_z = 8060 - 6293 = 1767 \text{ kg. cal.}$$

in the form of an identical vapour (in this case 56·3 per cent.) rising from plate L^1.

The vapour from the wash-column contains

$$a_e = 10 \text{ kg. and } w_m = 10 \times 0{\cdot}780 = 7{\cdot}80 \text{ kg.}$$

The spirit to be produced from this vapour contains

$$a_e = 10 \text{ kg. and } w_e = 10 \times 0{\cdot}166 = 1{\cdot}66 \text{ kg.}$$

Accordingly the weight of water to be separated in the lower part of the rectifying column L is

$$w_m - w_e = 7{\cdot}80 - 1{\cdot}66 = 6{\cdot}14 \text{ kg.}$$

The secondary heat required for the reflux in L is

$$C_u = \left(\frac{1767}{512{\cdot}8} \cdot 1{\cdot}01 + 6{\cdot}14\right)(102 - 90{\cdot}2) = 113{\cdot}5 \text{ kg. cal.}$$

According to Table 18, the heat required in a boiling-column to separate 100 kg. of water and vapour containing 56·3 per cent. (wt.) alcohol is at least 10,200 kg. cal., or in the present case $\frac{6{\cdot}14 \times 10{,}200}{100} = 626{\cdot}28$ kg. cal.

But we already have at our disposal 1767 kg. cal. (*v.s.*), which when calculated to 100 kg. of exhausted liquor becomes

$$\frac{1767 \times 100}{6{\cdot}14} = 28{,}778 \text{ kg. cal.}$$

Therefore, according to Table 19, section L of the rectifying column must be provided with six plates. The total heat-expenditure for a continuous apparatus with two adjacent columns which is to yield 90 per cent. (vol.) spirit from 100 kg. of 10 per cent. wash is, accordingly

$$C_h + C_m + \frac{C_u + C_{st}}{2} = 8963 \text{ kg. cal.}$$

$$C_z = 1767 \quad ,,$$

$$C_u = \frac{113{\cdot}5}{2} = 56{\cdot}7 \quad ,,$$

$$C_{st} = \frac{150}{2} = 75 \quad ,,$$

$$\text{Total} \quad 10{,}861{\cdot}7 \text{ kg. cal.}$$

This amount of heat is a little greater than that calculated for an apparatus with superimposed columns (10,804 kg. cal.), because, owing to the greater extent of surface, a little more heat will be lost by radiation.

Should an apparatus with adjacent columns be required to yield 94·6 per cent. (vol.) spirit, the heat-expenditure will be proportionately greater, exactly as it was in the case of superimposed columns.

Table 20 and Chart VIII give the alcohol-contents of liquid and vapour on plate M of boiling-columns when mixtures containing 1·0–80 per cent. (wt.) of alcohol flow on to it at temperatures varying from 0–80° C. below their boiling-points.

23. METHYL ALCOHOL AND WATER

A. Physical Properties

The considerations advanced and the equations developed in the foregoing sections can be used to ascertain the data of apparatus for separating methyl alcohol and water, if the physical constants of these substances are inserted in the equations.

The specific gravity (*s*) of methyl alcohol is 0·7984. The

specific gravities of its admixtures with water are approximately the same as those for mixtures of ethyl alcohol and water.

M. A. von Reis found the specific heat (σ) of pure methyl alcohol to be 0·6587

Temp.	5–10°	10–15°	15–20°	23–43°C.
σ	0·5901	0·5868	0·6009	0·6450

Mean value $\sigma = 0{\cdot}62425$.

E. Lecher [1] determined the specific heat of mixtures of methyl alcohol and water, and found :

Per cent. alcohol	12	20	31
$\sigma =$	1·073	1·072	0·980

Pure methyl alcohol boils at 66° C.

The approximate value of the latent heat of vaporisation of pure methyl alcohol at and above its boiling-point is found by applying Trouton's rule

$$L = \frac{24{\cdot}67 \,.\, T}{\mu} = 261{\cdot}4 \text{ kg. cal. per kg.}$$

where T is the absolute temperature and μ the molecular weight (32). Wirtz found the following values for the latent heat at various temperatures : [2]

0°	307·0	70°	264·5
50°	274·0	100°	246·0
60°	269·7	200°	151·8
64·7° . . .	267·5	230°	84·5

For information concerning the composition of the vapour evolved from mixtures of methyl alcohol and water, the author is indebted to Hilding Bergström (engineer), of Stockholm, and to Professors C. Blacher and Trschetziak, of Riga. That the values found by these investigators are fairly concordant is shown by the curves in Chart III, where the abscissæ give the composition of the liquid and the ordinates the composition of the vapour. Table 23 gives the compositions of mixtures and their vapours as found by Bergström and supplemented by the author (by interpolation from the curve), together with a few

[1] E. Lecher., *Sitzungsber. Akad. Wiss. Wien*, 1877, **76**, II, 937.

[2] J. Kendall (*Medd. K. Vetenskapsakad. Nobel-Inst.*, 1913, Vol 2, No. 36) found the following values for the latent heat of methyl alcohol at different temperatures :—289·2 at 0° C., 277·8 at 40°, 269·4 at 60°, 259·0 at 80°, 246·0 at 100°, 232·0 at 120°, 151·8 at 200°, 61·7 at 236°, 44·2 at 238·5°.—(TRANSLATOR.)

values which will be wanted in future calculations, exactly as was done in Table 2 for mixtures of ethyl alcohol and water. The weight of the methyl alcohol is represented by a, that of the water by w. The ratios $\frac{w}{a} = f$ and $\frac{w_d}{a_d} = f_d$ of the liquids and the vapours evolved from them are given in the columns adjacent to those containing the percentage weights of alcohol, a and a_d. As in Table 2, the values of the factors $\frac{(\alpha + f\beta)}{f - f_d}$ and $\frac{(\alpha + f_d\beta)}{f - f_d}$ have been calculated for each mixture with 1 kg. methyl alcohol, as they will be wanted in later calculations; in the evaluation of these factors, the latent heat of the pure methyl alcohol was assumed to be constant at 255, and that of the water at 550 kg. cal. per kg. Since the boiling-temperatures of the mixtures vary between 66° and 100° C., every mixture has a different boiling-point lying within this range of temperature. Apart from the fact that the boiling-temperatures of the various mixtures are not known with sufficient accuracy, it has been considered expedient, for the reasons given in the discussion on ethyl alcohol and water mixtures, to adopt a mean value for the latent heat of each component which corresponds approximately to the value at 85° C. The results are not much affected by this simplification, but where necessary, corrections can be introduced.

B. Apparatus for Periodic Rectification

The content of the boiling-vessel, in relation to the hourly output, should be as large as possible, in order that the distillation may continue uninterruptedly for a considerable period; in this way a better output of pure product is obtained, as was previously explained.

Table 25 and Chart X are useful for finding the data of columns and of the reflux condenser: the values have been calculated with the aid of equation (190) on the supposition that $a = 10$. This equation

$$C_a = \frac{a_e(f_a - f_e)(\alpha + f_B\beta)}{f_B - f_a} \quad . \quad . \quad . \quad . \quad (197)$$

gives the heat required to produce the final vapour $a_e + w_e$, of ratio f_e, from a mixture $a_A + w_A$, of which the vapour has

the ratio f_a, the reflux from the bottom plate having the ratio f_B. The nearer f_B approaches the ratio $\frac{w_A}{a_A} = f_A$, the smaller does C_a become, and in calculating the minimum heat-expenditure, f_B was, in fact, put $= f_A$ in equation (197).

In Table 24 and Chart V will be found the number of heat-units required to provide a product containing 1 kg. of methyl alcohol in the form of an 80, 90, or 99 per cent. vapour from mixtures containing 0·08–94·96 per cent. (wt.) of methyl alcohol. This table shows that more heat is required as the original liquid gets poorer in methyl alcohol, and that when this content is negligibly small, almost as much heat is required to make an 80 per cent. product as one containing 90 per cent.

Example.—If the original liquid contains:

50%	2% methyl alcohol

Then, by Table 23,

$f_A = 1$	49
$f_a = 0{\cdot}216$	5·759.

If the vapour of the product is to be 99% and contain 10 kg. methyl alcohol

$a_e = 10$	10
$f_e = 0{\cdot}0101$	0·0101

Therefore

$$C_a = \frac{10(0{\cdot}216 - 0{\cdot}0101)(255 + 1 \times 550)}{1 - 0{\cdot}216}$$

$$C_a = 2114 \text{ kg. cal.}$$

$$C_a = \frac{10(5{\cdot}759 - 0{\cdot}0101)\,(255 + 49 \times 550)}{49 - 5{\cdot}759}$$

$$C_a = 36{,}169 \text{ kg. cal.}$$

Towards the end of the distillation the alcohol-content of the liquid in the boiling-vessel becomes much reduced, and therefore the dimensions of the column, the number of plates in it, and the cooling surface of the reflux condenser must be so chosen that they are effective when the alcohol-content reaches the anticipated minimum. Since the heat-consumption of, and the work done by, a rectifying column depend mainly upon the number of plates used, we have given in Table 25 and Chart X the alcohol-contents of the vapour and liquid on each plate when 10,000–250,000 kg. cal. are set free in the reflux condenser in the production of 10 kg. of methyl alcohol as a 99 per cent. distillate. The calculation was performed in the manner shown in the appended example, and Chart IX was constructed from the results obtained.

Example.—10 kg. methyl alcohol leave the reflux condenser as 99% vapour. Therefore $a_e = 10$ kg., $w_e = 0{\cdot}101$ kg., and the ratio $f_e = 0{\cdot}0101$.

According to Table 23, the ratio of the reflux f_V must be 0·0303, and hence if 250,000 kg. cal. are abstracted in the reflux condenser, the reflux $a_V + w_V$ consists of

$$a_V = \frac{250{,}000}{255 + 0{\cdot}0303 \,.\, 550} = 920{\cdot}25 \text{ kg.}$$
$$w_V = 920{\cdot}25 \,.\, 0{\cdot}0303 = 27{\cdot}96 \text{ kg.}$$

The vapour which rises from the top plate consists of reflux vapour and the vapour of the product

$$a_s = a_V + a_e = 920{\cdot}25 + 10 = 930{\cdot}25 \text{ kg.}$$
$$w_s = w_V + w_e = 27{\cdot}96 + 0{\cdot}101 = 28{\cdot}06 \text{ kg.}$$

Its ratio is $\frac{w_s}{a_s} = f_s = 0{\cdot}03016$ (*i.e.*, 96·92%). Further, this vapour must have been evolved from a liquid on the top plate with a ratio $f_S = 0{\cdot}0965$ (Table 23).

Therefore the reflux from the top plate consists of

$$a_R = \frac{250{,}000}{255 + 0{\cdot}0965 \,.\, 550} = 811{\cdot}5 \text{ kg.}$$
$$w_R = 818 \,.\, 0{\cdot}0965 = 78{\cdot}31 \text{ kg.}$$

and so on.

Calculating in this way, we arrive at plate 7, where the vapour contains 2·61% and the liquid 0·35%; and we know from Table 25 that with a reflux heat of 250,000 kg. cal. the smallest possible alcohol-content of the vapour from the boiling-vessel is 2·6%.

Table 25 shows that with a smaller reflux heat, the minimum alcohol-content is greater, and that when $C_V = 10{,}000$ kg. cal. (for 10 kg. of methyl alcohol) the vapour of the product must contain at least 39·8 per cent. It also shows us that, contrary to experience with mixtures of ethyl alcohol and water, the action of the column is soon exhausted with very few plates, *i.e.*, rectifying columns for mixtures of methyl alcohol and water require but few plates; further, that the amount of reflux heat required depends almost entirely on the strength of the original liquid, and that for equal yields this amount of heat is greater than for ethyl-alcohol solutions. The methyl-alcohol content of the material in the boiling-vessel practically determines the heat-expenditure necessary to yield the product in a pure state. The surface-area of the reflux condenser must be sufficiently great to enable the heat C_V to be withdrawn from the vapour (the low boiling-point of methyl alcohol, 66° C., being also taken into consideration); and it is better to pass the vapour upwards, rather than downwards, through the reflux condenser.

C. Apparatus for Continuous Distillation (Continuous Separation)

Plate M, where the liquid enters the apparatus, is the starting-point for calculating the data of apparatus for continuous distillation, and the first task is to find the alcohol-content of the boiling liquid on it. We know that, under optimum conditions, this content depends solely on the amount of heat given up to this liquid by the vapour rising on to it from the lower part of the column, thereby raising its temperature to the boiling-point t_m. This amount of heat C_h is determined by the number of degrees by which the temperature of the original liquid falls short of the boiling-temperature. As previously found

$$C_h = \frac{a_e(f - f_M)(\alpha + f_m\beta)}{f_M - f_m} \quad . \quad . \quad . \quad . \quad (198)$$

where f_M is the ratio of the boiling liquid on plate M, and f_m the ratio of its vapour. The composition of the original mixture f, and the weight of methyl alcohol in it, are always given. The temperature t of the cold mixture, or t_v, that of the preheated mixture, and its boiling-temperature t_m on plate M, are either known or can be estimated, so that the heat C_h required to raise it to the boiling-point can be easily calculated. Lastly, the relationship between f_M and f_m is determined, because, under optimum conditions, these symbols represent the ratios of the liquid mixture and the vapour rising from it. Equipped with these data, the correct values of f_M and f_m can be ascertained after preliminary trial and by the aid of Table 23 (Chart III), in the sixth column of which the values of the factor $\frac{\alpha + f_m\beta}{f_M - f_m}$ are given.

Example.—100 kg. of a mixture containing 1% methyl alcohol are heated to 60° C. in the preheater, and then run on to plate M, where its boiling-temperature will be approximately 100°; the heat to be supplied to it will be

$$C_h = 100(100 - 60) = 4000 \text{ kg. cal.}$$

From Table 23 we learn that for a 1% solution $f = 99$.

Therefore $C_h = \frac{1(99 - f_M)(255 + f_m 550)}{f_M - f_m} = 4000$ kg. cal.

It is found by trial that the equation is satisfied when $f_M = 48, f_m = 5{\cdot}70$.

$$C_h = \frac{1(99 - 48)(255 + 5{\cdot}70 \,.\, 550)}{48 - 5{\cdot}7} = 4087 \text{ kg. cal.}$$

The actual alcohol-content of the liquid on plate M is thus about 1·99 per cent., and that of the vapour about 14·90 per cent.

Table 26 and Chart XI show the compositions of liquid and vapour on plate M for mixtures containing 0·5–15 per cent. of methyl alcohol which reach it at temperatures 0–90° C. below their boiling-point; they are very useful in determining the principal data of such apparatus.

To proceed with the determination: it will be remembered that in equation (68)

$$C_e + C_R + C_h = \frac{a_e(f - f_e)(\alpha + f_m\beta)}{f_M - f_m} \quad . \quad . \quad . \quad (199)$$

we deduced a relationship between the total heat-consumption of the apparatus and the ratios of the vapour and liquid on plate M; in this equation f, f_e, f_M, and f_m are used with the same meaning as in equation (198). By inserting in equation (198) the known values, we obtain the heat C_V required for the reflux in the rectifying column, after subtracting the values of C_e and C_h from the total on the left-hand side; and in doing this we must bear in mind that the equation holds only for the case of theoretical minimum heat-consumption. The question as to what happens when this optimum condition is unattainable, will be answered almost immediately; we must first work out a few examples on equations (198) and (199).

Example.—It is required to prepare a 99% wt. product ($f_e = 0{\cdot}0101$) from 100 kg. charges of various mixtures of methyl alcohol and water. Let these mixtures have the following alcohol-contents:

0·5%	1·5%	2%	7%	15%

Then the value of

$f =$ 199	65·67	49	13·186	5·66
$f - f_e =$ 198·99	65·66	48·99	13·176	5·65

The latent heat of the product for every 1 kg. of methyl alcohol is

$$255 + 0{\cdot}0101 \,.\, 550 = 260{\cdot}55 \text{ kg. cal.}$$

$C_e =$ 130·28	390·82	521·1	1823·85	3908 kg. cal.

If the crude liquor is boiling as it reaches plate M, $C_h = 0$, and the liquid on that plate remains identical with it; the vapour contains

3·8%	11·1%	14·8%	36·3%	57%.

The total heat-expenditure, according to equation (199) is

$C_e + C_R + 0 =$ 8110	8110	8110	9828	11,597 kg. cal.

The reflux heat $C_e + C_R + C_h - C_e - C_h = C_R$

$C_R =$ 7980	7720	7589	8004	7,689 kg. cal.

For 100 kg. spent wash (equation 190)

$C_a =$	8150	8230	8272	10,564	13,368 kg. cal.

If the liquid is 10° below boiling-point as it arrives on plate M: $C_h = 1000$ kg. cal.

Alcohol-content of vapour from M:

	4·2	12·5	16·1	39·4	58·6%
$C_e + C_R + C_h =$	8,130	8,130	8,420	10,227	12,225 kg. cal.
$C_R =$	6,997	6,740	6,200	7,404	7,317 ,,
$C_a =$	8,200	8,560	8,588	11,003	14,377 ,,

If the liquid is about 30° below boiling-temperature: $C_h = 3000$ kg. cal.

Vapour from M:	6·65	15·5	18·8	45	62%
$C_e + C_R + C_h =$	8,210	8,130	9,222	10,409	13,413 kg. cal.
$C_R =$	4,523	4,991	5,700	5,585	6,327 ,,
$C_a =$	8,300	8,560	9,404	11,189	15,127 ,,

If the liquid is about 50° below boiling-temperature: $C_h = 5000$ kg. cal.

Vapour from M:	9·95	19·6	24	50·8	65%
$C_e + C_R + C_h =$	8,300	9,329	9,604	11,627	14,708 kg. cal.
$C_R =$	2,970	3,876	4,094	4,800	5,800 ,,
$C_a =$	8,400	9,469	9,796	12,498	17,287 ,,

If the liquid is about 90° below boiling-temperature: $C_h = 9000$ kg. cal.

Vapour from M:	29	39	46	60·5	69·6%
$C_e + C_R + C_h =$	9,930	10,920	10976	14,091	17,775 kg. cal.
$C_R =$	797	1,530	1555	3,270	4,863 ,,
$C_e =$	10,000	11,100	12216	1,5141	20,940 ,,

To determine whether the values of C_R and C_a found above are concordant with those calculated from separate determinations, we give the following examples:

Example.—As above, the product $a_e + w_e$ is to be 10 kg. of 99% methyl alcohol ($f_e = 0{\cdot}0101$). The vapour from plate M contains:

	29%	46%	69·6%
$f_M =$	18·2	9·202	2·847
$f_m =$	2·449	1·174	0·439

Then, applying equation (24) for the reflux heat we obtain

$$C_R = 0{\cdot}5 \,.\, (2{\cdot}449 - 0{\cdot}0101) \,.\, 653{\cdot}9 = 797 \text{ kg. cal.}$$
$$C_R = 2{\cdot}0 \,.\, (1{\cdot}1711 - 0{\cdot}0101) \,.\, 661{\cdot}8 = 1555 \text{ ,,}$$
$$C_R = 15{\cdot}0 \,.\, (0{\cdot}439 - 0{\cdot}0101) \,.\, 755{\cdot}7 = 4866 \text{ ,,}$$

and these results agree exactly with those already found.

The heat to be used in the wash-column C_a is, in the three cases:

$$C_a = C_e + C_R + C_h = \frac{(99{\cdot}5 - 0{\cdot}015)(255 + 2{\cdot}449 \,.\, 550)}{18{\cdot}20 - 2{\cdot}449} = 9{,}945 \text{ kg. cal.}$$

$$C_a = C_e + C_R + C_h = \frac{(98 - 0{\cdot}0202)(255 + 1{\cdot}174 \,.\, 550)}{9{\cdot}202 - 1{\cdot}174} = 10{,}976 \text{ ,,}$$

$$C_a = C_e + C_R + C_h = \frac{(85 - 0{\cdot}1515)(255 + 0{\cdot}439 \,.\, 550)}{2{\cdot}847 - 0{\cdot}439} = 17{,}734 \text{ ,,}$$

Here also we find good agreement with the values previously obtained for $C_e + C_R + C_h = C_a$.

These examples show that the values for the reflux heat C_R and the total heat in the boiling-column $C_e + C_R + C_h$ are theoretically related, *i.e.*, the equations really give us the smallest heat-quantity which suffices not only to separate the water and to form weak alcohol-vapour in the boiling-column but also to convert that vapour into high-grade product in the rectifying column.

Occasional discrepancies, particularly in the case of vapours weak in alcohol (when it almost appears as if the heat-requirement is independent of the alcohol-content), are due to inaccuracies contained in Table 23, which are scarcely avoidable in view of the difficulties of experimental determination. Fortunately, such inaccuracies are of little practical importance.

After the heat required for the reflux has been determined, the data of the rectifying column can be calculated in precisely the same way as the data for apparatus working intermittently. The calculation must be continued until the alcohol-content on plate M is reached.

Data for a number of rectifying columns are given in Table 25, and the corresponding curves in Chart X.

Our calculations, based on the assumption of minimum heat-expenditure, have shown that the results required in practice can really be achieved by using the data we have determined; but at times, when aiming at perfect separation, or the production of a vapour of predetermined concentration, either on plate M or for the final distillate, calculation indicates the need of using more plates than are really desirable; in this case the number of plates can be reduced by the simple expedient of increasing slightly the supply of heat. The data in Table 27 will assist the worker in deciding upon the number of plates and the amount of heat to be used. This table, and Chart XII, show the alcohol-content of the vapours from all the plates in a boiling-column, when the heat expended is 13,000–100,000 kg. cal. for every 100 kg. of spent wash produced.

Example.—To show the manner of starting the calculation of a boiling-column in which 25,000 kg. cal. are used for every 100 kg. of spent wash containing 0·01% methyl alcohol.

The vapour from the spent wash contains 0·06% alcohol, and its ratio f_a is 1667. The weight of alcohol in this vapour is given by the equation :

$$C_a = a_a(255 + 1667 \,.\, 550) = 25{,}000 \text{ kg. cal.}$$
$$a_a = 0{\cdot}02725 \text{ kg. methyl alcohol}$$
$$w_a = 1667 \,.\, 0{\cdot}02725 = 45{\cdot}426 \text{ kg. water.}$$

The reflux from the bottom plate contains, in addition to this vapour, also 100 kg. water

$$a_R = 0{\cdot}02725 \text{ kg.} \qquad w_R = 145{\cdot}426 \text{ kg.}$$

Its ratio $\frac{w_R}{a_R} = f_R = 5333$ is also the ratio of the liquid on the bottom plate.

From this plate there ascends a vapour of ratio $f_d = 888$, the weight of which is given by

$$C_d = a_d(255 + 888 \,.\, 550) = 25{,}000 \text{ kg. cal.}$$
$$a_d = 0{\cdot}05116 \text{ (}i.e.\text{, } 0{\cdot}08\%\text{)}$$
$$w = 45{\cdot}430 \text{ kg.}$$

The reflux from the second plate contains an additional 100 kg. water, and its weight is therefore :

$$a_R = 0{\cdot}05116 \text{ kg.} \qquad w_R = 145{\cdot}430 \text{ kg.}$$

Its ratio $\frac{w_R}{a_R} = f_R = 2840$ is also that of the liquid on this plate, and from the latter there rises a vapour of ratio $f_d = 431$.

$$C_a = a_d(255 + 431 \,.\, 550) = 25{,}000 \text{ kg. cal.}$$
$$a_d = 0{\cdot}1054 \text{ kg.} \qquad w_d = 45{\cdot}248 \text{ kg.}$$
$$a_R = 0{\cdot}1054 \text{ kg.} \qquad w_R = 145{\cdot}248.$$

Hence $f_R = 1378$, and this reflux gives a vapour of ratio 270 . . . and so on.

The curves in Chart XIII have been constructed from data given in Tables 25 and 27 and Charts X and XII; they will be useful for finding the alcohol-content on any plate when the heat-expenditure lies within the values used in calculating these tables. Each curve in Chart XIII gives the alcohol-content of the vapour rising from the plate whose number is inscribed on it for a reflux-heat expenditure lying between 10,000 and 250,000 kg. cal. and for 1 kg. of alcohol in the rectifying column : also for a total heat-expenditure lying between 1400 and 100,000 kg. cal. for every 100 kg. of water run off from the boiling-column. As the alcohol-contents on the lowest plates are very small, the curves for these have not been included.

The following summary outlines the method used for calculating the data of apparatus for continuous distillation :—

(*a*) Determination of the alcohol-content on plate M, using equation (198) and data from Table 23 and Chart XI.

(*b*) Calculation of the smallest possible total heat-expenditure $C_a = C_e + C_h + C_V$, using equation (199).

(*c*) Subtraction of C_e and C_h from this total to ascertain the reflux heat C_R.

(*d*) Re-calculation of C_R for 10 kg. of alcohol, and of C_a for 100 kg. of spent wash.

(*e*) Reference to the tables to find out if, when a suitable number of plates is used, these smallest possible heat-quantities suffice for the production of a vapour of the desired alcohol-content on plate M of the boiling-column, and of a final vapour of the predetermined strength in the rectifying column.

(*f*) If these heat-quantities are insufficient for the purposes named, the total heat-expenditure must be increased to the extent demanded by the number of plates selected. The additional heat supplied to one column must, of course, be included in the calculations of the other column.

24. ACETONE AND WATER

A. Physical Properties

The specific gravity of pure liquid acetone is 0·7921.

The specific heat of the liquid was found by Weidner to be 0·3468 between 26·2° and 110° C., and 0·3740 between 27·3° and 179·3° C.

The specific heat of the vapour, determined by Regnault, is 0·4125.

The boiling-point under normal pressure is 56·7° C.

The latent heat of vaporisation of acetone (α) will be taken as 125·28, and that of water (β) as 537. Critical temperature of acetone vapour: 232·8–237·5–234·4–246·1° C.

The composition of the vapour evolved from acetone-water solutions has been determined experimentally and published by H. Bergström,[1] of Stockholm.

B. Apparatus for Continuous Distillation

The physical constants enumerated above have been used in the calculations that follow, and the values given in Table 30 are based upon the results obtained by Bergström and others. The figures given in column 7 of this table represent the heat-expenditure C_a required to produce 1 kg. of exhausted liquor in the boiling-column when the mixture to be separated has the composition indicated in the same line of column 2. The heat-consumption for 100 kg. of original liquid is obtained by multi-

[1] H. Bergström, *Aftryk ur Bihang till Jern-Kontorets Annaler*, 1912. See also H. R. Carveth, *J. Physical Chem.*, 1899, 3, 193, and J. H. Pettit, *ibid.*, 1899, 3, 349.

plying the figures given in column 7 by the weight of the exhausted liquor $(w - w_e)$.

The latent heat of the reflux required in the rectifying column is given by the equation

$$C_R = C_V = \frac{a_e(f_d - f_e)(\alpha + f_R\beta)}{f_R - f_d} \quad . \quad . \quad . \quad (200)$$

The values of this heat-requirement are obtained by multiplying the figures in column 6 of Table 30 by $(f_d - f_e)$; they are inserted in Table 31 and included in Chart XIV. In addition to the reflux-heat requirement for producing 1 kg. of acetone as 95–99·75 per cent. vapour, Table 31 also gives the heat required in the boiling-column to separate 100 kg. of water as spent liquor from acetone-water mixtures.

In the preparation of very high-grade acetone, the amount of reflux heat required in the rectifying column varies considerably. This phenomenon is probably due to the physical properties of the substances. In using Table 31 for calculating the data of apparatus, one should select the highest value of C_R if the alcohol-content lies between two consecutive values given in the table.

In Tables 32 and 33 is given the required information concerning the number of plates to be used in the rectifying column or the boiling-column, the calculation being performed from plate to plate, as previously explained. We learn from them that more heat is required in the boiling-column than in the rectifying column.

Appended are three examples illustrating the use of the tables in determining the data of apparatus for the continuous separation of acetone-water mixtures.

Examples.—

		(1)	(2)	(3)
Weight of acetone-water mixture	=	100	100	100 kg.
Content of acetone	=	5	10	20%
Ratio	f =	19·2	9·0	4·0
Desired acetone-content of product	=	99·75	99·75	99·75%
i.e., acetone	a_e =	5·0	10·0	20·0 kg.
water	w_e =	0·01257	0·02515	0·0503 ,,
spent liquor $w - w_e$ . . .	=	94·4875	89·973	79·949 ,,
Heat needed to raise 100 kg. mixture to b.-pt.	C_h =	3000	3000	3000 kg. cal.
Acetone-content of the liquid on plate M	=	15·75	21·5	31·4%
Ratio	f_M =	5·30	3·651	2·19

Examples—

		(1)	(2)	(3)	
Acetone-content of vapour from plate M	=	84·7	88·29	91·2%	
Ratio	f_m =	0·18	0·133	0·0975	
Ratio of vapour of product . .	f_e =	0·002515	0·002525	0·002515	
Heat of vapour of product . .	C_e =	a_e (125·28+0·002515 . 537)			
	C_e =	633	1266	2532 kg. cal.	
Total heat-expenditure . . .	C_a =	$\frac{a_e(f - f_e)(\alpha + f_m\beta)}{f_M - f_m}$			
$C_e + C_R + C_h$ =	C_a =	4120	5000	6714	,,
Reflux heat $C_R = C_a - C_e - C_h$ =		487	733	1181	,,
Value of C_R for 10 kg. acetone .	C_R =	974	733	591	,,
Total heat for 100 kg. spent liquor	C_a =	4320	5570	8540	,,

These results agree well with the data given in Tables 30 and 31, but for practical use it must be borne in mind that, in conformity with the very convex shape of the vapour-composition curve, the reflux heat must be assumed to be greater and, in fact, to be equal to the greatest value of C_R required for vapours from 84·7, 89·97, or 91·2 per cent. up to 99·75 per cent. According to Table 31, this value of C_R is 1330 kg. cal. for 10 kg. of acetone. Actually, therefore, the smallest heat-expenditure for 100 kg. of each of the above mixtures is, respectively,

(1)	(2)	(3)
C_e = 633	1266	2532 kg. cal.
C_h = 3000	3000	3000 ,,
C_R = 665	1330	2660 ,,
= 4298	5596	8192 kg. cal.

Calculated on 100 kg. of spent liquor $(w - w_e)$ these amounts become

C_a = 4549	6219	10,252 kg. cal.

Tables 32 and 33 indicate that it is better in practice to use rather more heat than the calculated minimum, in order that the number of plates in, and therefore the height of, the columns may be reduced.

25. ACETONE AND METHYL ALCOHOL

The physical constants of these substances have already been given in the two preceding sections. Two papers have been published dealing with the composition of the vapour from mixtures of acetone and methyl alcohol, of which the earlier is

that of Pettit.[1] This investigator determined the boiling-points of liquid mixtures under 760 mm. pressure and found :

Methyl alcohol.	Boiling-temperature.	Methyl alcohol.	Boiling-temperature.	Methyl alcohol.	Boiling-temperature.
% wt.	°C.	% wt.	°C.	% wt.	°C.
100·0	65·52	51·9	58·34	18·6	56·09
89·1	63·44	49·0	58·02	13·2	55·99
80·5	61·98	45·0	57·65	6·6	56·09
58·6	58·96	31·0	56·68	0·0	56·62
53·7	58·52	23·1	56·29		

He then distilled the mixtures and determined simultaneously the boiling-points of the residual liquid and of the liquid obtained by condensing the evolved vapour.

Boiling-points.		Boiling-points.		Boiling-points.	
Solution.	Liquefied vapour.	Solution.	Liquefied vapour.	Solution.	Liquefied vapour.
°C.	°C.	°C.	°C.	°C.	°C.
56·67	56·40	56·54	56·08	61·67	59·29
56·48	56·30	56·94	56·15	62·47	60·17
56·28	56·14	57·04	56·27	62·89	60·63
56·22	56·10	57·46	56·45	63·33	61·31
56·17	56·08	58·52	56·91	63·77	61·83
56·02	55·98	58·77	57·07	64·46	62·93
56·16	55·93	59·17	57·47	64·76	63·43
56·30	55·95	59·77	57·71	64·97	63·77
56·40	55·95	60·77	58·47	65·22	64·49

Using the above data the author has constructed the curve given in Chart XV, which correlates the acetone-content of the liquid with that of the vapour; and from this curve he derived the values inserted in columns 2 and 4 of Table 34. It appears that when the solution attains an acetone-content of about 12–15 per cent.,[2] the boiling-temperatures (and therefore also the compositions) of liquid and liquefied vapour are the same, so that separation by repeated vaporisation can only be carried out up to this point.

[1] J. H. Pettit, *J. Physical Chem.*, 1899, **3**, 340.
[2] Bergström gives 10 per cent. as the limiting concentration.

Table 35 shows the reflux heat C_R required in the rectifying column to produce 1 kg. of acetone in distillates containing 50–60–70 per cent. of it; and Table 34, column 7, gives the total heat required in the boiling-column to separate 1 kg. of methyl alcohol in the liquid discharged at the base of the column.

The calculated data for rectifying and boiling-columns are incorporated in Tables 36 and 37, respectively. Both give the acetone-content of the liquid and vapour on every plate; Table 36 for the production of distillates containing 50–60–70 per cent. acetone, if 8000–40,000 kg. cal. are used for every 10 kg. of acetone recovered, and Table 37 for an expenditure of 10,000–50,000 kg. cal. per 100 kg. of acetone-free methyl alcohol. These tables are to be used in determining the number of plates required in any column.

H. Bergström[1] has recently published a curve, based on direct observation, and which is therefore quite reliable, representing the acetone-content of vapours from mixtures of methyl alcohol and acetone. The data and curve are reproduced in Table 34 and Chart XV, respectively, adjacent to those of Pettit. Bergström's values for the acetone-content of the vapours are somewhat lower than Pettit's; but the differences are not important, and any slight change in the work of separation necessitated by them can easily be found by calculation.

26. METHYL ALCOHOL AND ETHYL ALCOHOL

The physical data concerning these substances have already been given. To H. Bergström the author is indebted for the vapour-composition curve of this mixture, with the aid of which Table 39 has been compiled, and therefrom Table 40 for determining the number of plates required in the column. The values used for the latent heats were $\alpha = 262$, $\beta = 243$. The resolution of these mixtures requires an exceptionally large amount of heat, especially when the content of methyl alcohol is low.

[1] H. Bergström, *Aftryk ur Bihang till Jern-Kontorets Annaler*, 1913.

27. ACETIC ACID AND WATER

The specific gravity of acetic acid at 20° C. is 1·0497.

The specific heat of the pure liquid acid is 0·5265 (Berthelot gives 0·5357 for 18–111°, and 0·522 for 26–96°).

G. C. Schmidt found the following values for the specific heat of mixtures of acetic acid and water [1]:

Acetic acid. % wt.	Specific heat.	Acetic acid. % wt.	Specific heat.	Acetic acid. % wt.	Specific heat.
100	0·5265	60	0·7159	10	0·9527
90	0·5738	50	0·7632	1	0·999
85	0·5901	40	0·8106	0	1·000
80	0·6212	30	0·8579		
70	0·6685	20	0·9053		

The specific heat of the vapour of acetic acid is 0·4008.

The boiling-temperature is 118·7–119·2° C.

Different values have been given for the latent heat of vaporisation: Brown [2] gives 97·05, Berthelot [3] 84·9, Marshall and Ramsay [4] 97. In our calculations the latent heat of vaporisation of water (in this case the low-boiling component) is assumed to be $\alpha = 529$, and that of acetic acid $\beta = 75{\cdot}5$; the latter figure is perhaps somewhat too low.

The composition of the vapour from mixtures of these two substances is known from the observations of Blacher,[5] of Riga, O. Fagerlind,[6] of Stockholm, and of Lord Rayleigh,[7] whose results are in good agreement, as will be seen in Table 42 and

[1] See M. A. von Reis, *Ann. Physik* (*Wiedemann*), 1880, **10**, 291; Ch. Lüdeking, *ibid*, 1886, **27**, 72.

[2] J. C. Brown, *J. Chem. Soc.*, 1903, **83**, 987. By Trouton's Rule $\frac{\mu L}{T} = 14{\cdot}88$.

[3] M. Berthelot and Ogier, *Ann. Chim. Phys.*, 1883, (5), **30**, 382, 400, 410.

[4] D. Marshall and William Ramsay, *Phil. Mag.*, 1896, (5), **41**, 38. See also W. Louguinine, *Ann. Chim. Phys.*, 1896, (7), **7**, 251; 1902, **26**, 228; **27**, 105; also *Arch. Sci. phys. nat.* (*Bibliothèque Universelle Genève*), 1900, **9**, 5. Trouton's rule gives $\frac{\mu L}{T} = 13{\cdot}74$.

[5] Private communication.

[6] *Aftryck* [illegible] *Jern-Kontorets Annaler*, 1912.

[7] Lord [illegible] *Mag.*, 1902, (6), **4**, 521.

Chart III. Since the vapours from mixtures of acetic acid and water contain more water than the liquid mixtures, the water-content (and not the acetic-acid content) of the liquid and the vapour are given in the table and the chart.

Table 43 and Chart V give, in the usual way, the heat-quantities required (*a*) for the reflux in the rectifying column, in order that steam with only 0·1 per cent. of acetic acid may be driven over from liquids containing 97–0·5 per cent. of water (3–99·5 per cent. of acetic acid); (*b*) to produce at the base of the boiling-column acetic acid containing practically no water, while the mixture with 0·5–97 per cent. water flows on to plate M. The heat-expenditure is high compared with that required for other liquid mixtures.

Table 44 shows the percentage of water in the liquids on and in the vapours from each plate in five rectifying columns; each column produces from a mixture containing 8·0, 4·85, 2·33, 0·99, or 0·58 per cent. of water, a distillate of 10 kg. water containing 0·1 kg. acetic acid, the reflux-heat expenditure being 20, 23, 40, or 150 thousand kg. calories. This table, like the previous one, also shows that considerable quantities of heat must be used for separating water and acetic acid. Table 45 gives the water-content of liquids and vapours on each plate in boiling-column when the heat-expenditure therein ranges from 80 thousand to 4 million kg. cal. per 100 kg. of acetic acid discharged at the base of the column.

28. FORMIC ACID AND WATER

The specific gravity of formic acid is 1·2273; the specific heat of the liquid acid is 0·552 (Berthelot). Formic acid boils at 99·9° C. (100·4° is sometimes stated[1]) under 760 mm. pressure. The latent heat is 103·7 (Berthelot); for our calculations the values α (water) = 537 and β (formic acid) = 103·7 have been employed.

As a rule, the vapour evolved from a mixture of formic acid and water has a higher water-content than the mixture. Consequently, as with acetic acid and water, separation must be effected in such a way that the water, as free from acid as possible,

[1] The best authorities now give the b.-pt. as over 100° C., *e.g.*, Landolt-Börnstein gives 101° C.—(TRANSLATOR.)

leaves the reflux condenser as steam, and the water-free acid either remains behind in the boiling-column or is run off from its base. Table 46 and the corresponding curve in Chart III show the relation between the water-contents of the liquid mixture and of its vapour; Bergström's[1] data have been used in their construction.

To conform with the method of presentation adopted in this work, and to give prominence to the low-boiling component, Bergström's table and the curve corresponding to it have been extended slightly by the author and transformed so as to show the water-content, and not the content of formic acid, of the liquids and their vapours. In Table 46 the calculated values of f, f_d, $\frac{\alpha + f\beta}{f - f_d}$, and $\frac{\alpha + f_d\beta}{f - f_d}$ are also inserted.

Bergström's results show that only liquid mixtures containing 25 per cent. or more of water yield vapours containing more water than they themselves possess, and that for mixtures containing less than 25 per cent. of water the composition of the vapour is the same as that of the liquid: hence 75 per cent. is the maximum content of formic acid either in the boiling-vessel or in the mixture run off from the base of continuously working apparatus. To distil off 10 kg. of water containing 0·4 per cent. of formic acid from weaker mixtures necessitates, as Table 46 shows, a large amount of reflux heat, and therefore is always costly. Also noteworthy is the large and widely fluctuating amount of heat required to separate 1 kg. of formic acid in the boiling-column (Table 48, and Table 46, last column, calculated to 100 kg. formic acid).

Table 49 gives the water-content of the liquid and vapour on each plate in rectifying columns when a final vapour with 99·8 per cent. water is produced with a reflux-heat expenditure of 5000–200,000 kg. cal. for every 10 kg. of water (containing 0·2 per cent. formic acid) evaporated. In Table 50 will be found the water-content on the plates of boiling-columns when the total heat employed in vaporising is 150,000–700,000 kg. cal. for every 100 kg. of acid (containing 33·3 kg. water) run off at the base.

[1] H. Bergström, *Aftryk ur Bihang till Jern-Kontorets Annaler*, 1912.

29. AMMONIA AND WATER

A. Physical Properties

The density of gaseous ammonia is 0·58957 when air = 1 (0·5894 is also given).

At constant pressure the specific heat of the gas is 0·5084 (Regnault); at 0° C. it is 0·5009, and at 100° C. 0·5317 (E. Wiedemann).

According to Drewes the specific heat of liquid ammonia is:

Temp.	0°	10°	20°	30°	40°	50°	60°	70° C.
σ	0·876	1·140	1·190	1·218	1·231	1·239	1·240	1·233

The boiling-point of pure ammonia was found by E. C. Franklin[1] to lie between − 32·5° and − 33·5° C.

The vapour-pressure was determined by L. Grätz[2]:

° C.	mm.	° C.	mm.	° C.	mm.
− 30	866·1	+ 10	4574	+ 50	15,158
− 20	1392·1	+ 20	6387·8	+ 60	19,482
− 10	2144	+ 30	8700	+ 70	24,670
0	3280	+ 40	11,595	+ 80	30,840

The solubility of ammonia in water was investigated by Bunsen[3]; the absorption coefficient as given by him is

$$C = 1049 - 29{\cdot}499t + 0{\cdot}67687t^2 - 0{\cdot}0095621t^3.$$

Tables of values are also given by Sims,[4] Roscoe and Dittmar,[5] and Raoult.[6] The following table compares the values of Bunsen and Raoult:

Temp.	0°	4°	8°	12°	16°	20°	24° C.
Bunsen	44·44	41·744	37·186	35·186	35·186	33·278	31·388%
Raoult	49·74	42·049	39·758	37·403	35·154	34·105	31·258%

The heat of solution of 1 kg. of ammonia in excess of water was found by Thomsen[7] to be 496 kg. cal., and by Raoult[6] to be 492 kg. cal.

[1] E. C. Franklin, *Ann. Physik* (*Wiedemann*), 1907, **24**, 367.
[2] L. Grätz, Winkelmann's "Handbuch der Physik."
[3] R. Bunsen, "Gasometrische Methoden," 1st edition, 1857.
[4] T. H. Sims, *Ann. Chem. Pharm.*, 1861, **118**, 348.
[5] Roscoe and Dittmar, *J. Chem. Soc.*, 1860, **12**, 147.
[6] F. M. Raoult, *Ann. Chim. Phys.*, 1874, (5), **1**, 262.
[7] J. Thomsen, "Thermochemische Untersuchungen" (Thermochemical Investigations), Vol. 2, p. 68.

According to Regnault the latent heat of vaporisation of pure ammonia is 295 (other investigators give values between 291·3 and 297·38 for the temperature-range 7–16° C.). Perman [1] states that from 13° C. upwards the latent heat of ammonia-water mixtures is equal to the sum of the individual latent heats, because in the gaseous state the two substances are mutually indifferent. Perman's figures are as follows :

Ammonia :	10	12·5	15	17·5	20	22·5	25	27·5	30%
Latent Heat :	560	552	545	537	530	523	515	508	501.

The vapour-pressures (kg. per sq. cm.) of aqueous solutions of ammonia were determined by H. Mollier,[2] as follows :

% NH_3	20°	30°	40°	50°	60°	70°	80°	90°	100°	110°	120°	130°	140°	150°C.
5	—	—	—	—	—	—	0·925	1·32	1·83	2·49	3·33	4·49	5·71	7·28
10	—	—	—	—	—	1·05	1·48	2·07	2·80	3·75	4·92	6·35	8·01	10·20
15	—	—	—	—	1·12	1·58	2·20	2·99	3·99	5·24	6·77	8·64	—	—
20	—	—	—	1·14	1·63	2·27	3·09	4·15	4·48	7·08	9·19	—	—	—
25	—	—	1·14	1·64	2·28	3·14	4·24	5·64	7·34	9·45	—	—	—	—
30	—	1·13	1·63	2·28	3·16	4·20	5·71	7·49	9·62	—	—	—	—	—
35	1·08	1·57	2·25	3·14	4·27	5·76	7·57	9·73	—	—	—	—	—	—
40	1·50	2·17	3·07	4·24	5·70	7·55	9·70	—	—	—	—	—	—	—
45	2·02	2·91	4·08	5·55	7·36	9·56	—	—	—	—	—	—	—	—
50	2·66	3·79	5·24	7·09	9·26	—	—	—	—	—	—	—	—	—

The partial pressure of the ammonia p_{at} is given by the equation :

$$\frac{P}{p_{at}} = \frac{\dfrac{100 - a}{m_w}}{\dfrac{a}{m_a} + \dfrac{100 - a}{m_w}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (b)$$

where P is the total pressure of the mixture (water and ammonia); $m_a = 17$, $m_w = 18$, the molecular weights of ammonia and water respectively; and a the percentage of ammonia in the liquid mixture.

For any given total pressure P (*e.g.*, atmospheric pressure), the partial pressure of the ammonia can be found from this equation, and hence, if the vapours behave as gases, the proportion by weight of ammonia in the mixed vapours.

The latent heat L has been calculated by Mollier from Clapeyron's equation

$$L = A \,.\, T \,.\, v\left(\frac{dP}{dT}\right)_x \quad . \quad . \quad . \quad . \quad . \quad (a)$$

[1] E. P. Perman, *J. Chem. Soc.*, 1903, **83**, 1168.
[2] Hilde Mollier, *Mitteil. über Forschungsarbeiten* 63/64, and *Z. Ver. deutsch. Ingen.*, 1908, **52**, 1315.

in which L represents the heat consumed when 1 kg. of mixture is vaporised at constant temperature. L, therefore, includes both the latent heat of ammonia and that of the water present as vapour in the mixture. T is the absolute temperature, v the increase in volume [accompanying the transformation from the liquid to the gaseous state], and P the total pressure of the vapour-mixture expressed in atmospheres. [A is the value of the mechanical equivalent of heat]. The values of $\left(\frac{dP}{dT}\right)$ were obtained from a series of curves which were based upon the experimental investigation of total vapour pressures (500–7500 atm.) of liquids of the same composition (11·80, 22·39, 33·73, 41·45, 50·36 per cent. ammonia) but of different temperatures (20–120°). The following table gives values of the latent heat L of 1 kg. ammoniacal liquor of various strengths and at different temperatures, as calculated by Mollier (equation a).

Ammonia-content of solution	11·8%	23·39%	33·75%	41·5%	50·30%	100%
Temp.						
20°	—	—	—	382	354	280
30°	—	—	394	371	350	272
40°	516	451	400	372	358	257
50°	496	428	385	309	345	—
60°	456	405	381	350	309	—
70°	480	431	405	358	—	—
80°	490	429	388	—	—	—
90°	470	424	378	—	—	—
100°	464	420	—	—	—	—
Values of L calc. from eq. (a)	471	426	393	375	353	—

The water-content of the vapour-mixture is then found by an equation given by Raoult, its latent heat is subtracted from the total latent heat L to find the latent heat of the ammonia, and the value so obtained is recalculated to 1 kg. of ammonia:

Ammonia-content of Solution.	11·8%			23·39%			33·73%		41·55%		50·36%
Temperature.	40°	70°	100°	40°	70°	100°	40°	70°	40°	70°	40°
Total pressure (mm.)	282	898	2360	743							3910
Partial press. of water	48	204	665	42							27
Water in vapour (wt. %)	18	24	29	6							0·7
Latent heat: of water alone	104	132	157	35	50	66	14	22	8	11	4
Latent heat: of soln. by equation (a)	471	471	471	426	426	426	393	393	375	375	353
Latent heat: of ammonia alone	L=367	339	314	391	376	360	379	371	367	364	349
Latent heat: of ammonia per kg.	**447**	**446**	**442**	**416**	**413**	**410**	**389**	**386**	**372**	**371**	**354**

According to Mollier the process of condensation and solution of 1 kg. ammonia gas in water or weak mixtures at 100° may be treated as follows :

By self-cooling from 100° to − 33°, 1 kg. ammonia liberates	$1 \times 133 \times 0{\cdot}5$	=	66·5 kg. cal.
Heat set free on liquefaction . . .	1×329	=	329·0 ,,
Heat of solution of liquid ammonia .	1×188	=	188·0 ,,
Heat taken up by self-heating to 100° .	1×133	=	− 133·0 ,,
Heat of solution and vaporisation . .			450·5 kg. cal.

The assumption that the specific heat of ammonia is unity appears to be justified, because the concentrations of the ammonia solutions here considered are only 0–4 per cent. and the heating up begins at − 33° C. It will also be conceded that, owing to the liquids being very weak and the vapours far from rich, the magnitude of the latent heat of ammonia, in contrast with that of the large amount of water, cannot have any appreciable effect on the changes that take place in the apparatus.

Lord Rayleigh [1] appears to be the only investigator who has published results relating to the ammonia-content of the vapours evolved from ammonia–water mixtures; his curve, given in Chart III, was not regarded by him as very accurate, but, in the absence of other information, his data have been used in compiling Table 51.

Since the mixtures to be distilled are seldom richer than 4 per cent., and the vapours therefore seldom contain more than 30 per cent. of ammonia, their boiling-temperatures will usually be very near 100° C., and therefore the latent heat of the water present may be taken as 536. In calculating the tables 450 kg. cal. has been taken as the heat of solution and vaporisation of 1 kg. of ammonia.

B. Apparatus for Continuous Distillation

The equation $C_R = \frac{a_e(f_d - f_e)(\alpha + f_R\beta)}{f_R - f_d}$ has been used to calculate the heat-requirement of the reflux in the rectifying column for the production of 1 kg. of ammonia, in the form of vapour containing 20, 25, and 30 per cent., from liquids of widely

[1] Lord Rayleigh, *Phil. Mag.*, 1902, (6), 4, 533.

differing composition, and the values obtained are given in Table 52. This table shows how greatly the heat-consumption increases as the content of ammonia in the original liquid declines and as that of the product increases.

The heat required in the boiling-column for every 100 kg. of exhausted liquid is found from the equation

$$C_a = \frac{100(\alpha + f_d\beta)}{f_R - f_d}.$$

The values of C_a for 1 kg. of exhausted liquid can be derived from the figures in column 6 of Table 51. C_a remains about the same whether it is required to produce on plate M a vapour of 1 per cent. or one of 30 per cent. from practically exhausted liquid. Theoretically, about 7000 kg. cal. are needed for 100 kg. of spent liquor.

Table 53 gives the number of plates required in the rectifying column when 10 kg. of ammonia are recovered as 20 and 30 per cent. vapour respectively for reflux-heat expenditures of 3500, 5000, 10,000, 15,000, 20,000, 25,000, and 50,000 kg. cal. We learn from it that in all cases three plates only are required to produce the desired concentration of the distillate, but that the smallest value of C_R, viz., 3500 kg. cal., is only suitable when the original liquid flowing on to plate M contains at least 2·26 per cent. of ammonia, whilst the highest value, 50,000 kg. cal., permits of a high-grade distillate being produced from a 1·05 per cent. liquid. The data for a boiling-column contained in Table 54 (C_a = 8000–10,000 kg. cal. per 100 kg. of spent liquor) show that if it be required to keep the number of plates within convenient limits, the heat employed must be considerably greater than the lowest amount theoretically required, and that in apparatus for the continuous separation of ammonia, the boiling-columns should never be very short.

In Table 55 are given the chief data for apparatus in which final vapours of 20, 25, and 30 per cent. are produced from liquids containing 1·5, 2, 2·5, and 3 per cent. The procedure adopted in compiling the table has already been explained, and in this case two different initial temperatures of the ammoniacal solution have been taken, namely :

(*a*) the temperature of plate M, *i.e.*, $t = t_m$ and $C_h = 0$. In this case the composition of the liquid does not alter; $f = f_m$ and C_R is found directly with the help of equation (199);

(*b*) the preheating temperature is so low that when the original liquid arrives on plate M it becomes considerably enriched by the vapours $a_h + w_h$ which reach the plate from below and condense on it. It is assumed that this enrichment is sufficient to cause the evolution of a vapour having the same ammonia-content as the distillate. The value of C_h required for this purpose was obtained by inserting in equation (90) the known values of f_M and f_m.

The table gives the reflux heat C_R for 10 kg. ammonia and the total heat C_a for 100 kg. of exhausted liquor. We learn from it (1) that C_a is practically the same in all cases, *i.e.*, about 7000 kg. cal. (theoretically); and (2) that neither the latent heat of the product C_e taken alone, nor in conjunction with that of the reflux, is sufficient to raise the temperature of the crude liquor to its boiling-point.

30. NITROGEN AND OXYGEN (AIR) [1]

Mixtures of liquefied gases can be separated by repeated vaporisation in exactly the same way as other liquid mixtures: the general principles involved, the requirements and the mode of operation of the apparatus, are identical. Nevertheless a number of new factors has to be considered owing to the very low temperatures at which distillation must be performed, the production and maintenance of which are very costly both in time and money; on the other hand the cost of supplying heat to the apparatus is saved. Continuous apparatus is always preferable to periodic apparatus for separating in the pure state one of the two constituents of air, because it is more suitable for treating small quantities, heat can be utilised more economically, and there are no residual products to be worked up.

It is proposed to consider only the chief constituents of air, oxygen (*o*) and nitrogen (*n*); the small admixtures of other gases will be neglected. As the method of treatment is the same as that used hitherto, it will only be necessary to consider a few outstanding points.

[1] See also Dr. H. Alt, "Die Kälte, ihr Wesen, ihre Erzeugung und Verwertung" (Cold, its Nature, Production, and Utilisation).

Appended are some important physical constants :

	Air.	Oxygen.	Nitrogen.	Argon.
	l	o	n	a
Percentage composition by weight	100	23·1	76·9	[1·296]
Percentage composition by volume	100	20·99	79·01	[0·95]
Atomic weight	—	15·88	14·04	39·9
Density (gas)	1	1·1056	0·9713	1·3770
,, (liquid)	1	1·131	0·791	1·4233
Sp. heat of gas at constant pressure	0·241	0·2175	0·2438	0·123
Sp. heat of gas at constant volume	0·169	0·1548	0·1735	0·074
Sp. heat of liquid	0·411(?)	0·347	0·430	—
Weight in kg. of 1 cb. m. of gas at 0° C. and 760 mm.	1·2935	1·4292	1·2546	1·782
Absolute boiling-point under 760 mm.	77—90°	90·2°	77·3°	86·9°
Boiling-point, °C.	− 183 to − 194°	− 182·8°	− 195·7°	− 186·1°
Critical temp. abs.	133°	154·2°	127°	155·6
Critical pressure	39	50·8	35	52·9
Solidifying-point, abs.	—	46°	62·5°	83·4°
Pressure at abs. solidifying-point (mm. mercury)	—	0·9	94	—

The weights of 1 cubic metre and the volumes of 1 kg. of air, oxygen, and nitrogen, at low temperatures, are given in Table 56. Nitrogen is the low-boiling component of air, and therefore it is given precedence in the calculations. Baly [1] has published a table showing the oxygen-content and boiling-temperature of the vapours evolved from various liquid mixtures of nitrogen and oxygen, and the author has used his figures for calculating the corresponding values for nitrogen, and has amplified them with the aid of the curve given in Chart XV. These amplified data are given in columns 1, 2, and 4 of Table 57, where the original figures of Baly are marked by asterisks.

The figures in columns 2 and 4 of the same table represent percentages by volume; they can be converted into percentages by weight by multiplying with $\frac{100}{1 + \frac{os_o}{ns_n}}$, where n and o signify

[1] E. C. C. Baly, *Phil. Mag.*, 1900, (5) 49, 517.

respectively percentages by volume, and s_n, s_o the densities of these gases. If Baly's original figures (Table 57) are converted in this way, it will be seen from the appended table that the percentages by weight are only about 1·65 per cent. greater than the corresponding percentages by volume. For the values derived from Table 57, the differences are only about 0·5–1·0 per cent.

Percentages by Weight of Nitrogen in Liquids and Gases

Liq.	Gas.	Liq.	Gas.	Liq.	Gas.	Liq.	Gas.
100	100	53·47	80·5	27·95	56·4	11·037	28·27
90·9	97·5	48·7	77·2	25·15	52·6	9·091	25·63
82·75	95·13	44·55	74·3	22·59	48·5	7·142	20·55
76·3	92·4	40·86	70·8	19·85	44·7	5·263	15·45
69·7	89·6	37·55	67·35	17·68	40·57	3·389	10·20
63·73	86·9	34·24	63·70	15·41	36·45	1·090	4·90
58·3	83·5	31·05	58·0	13·03	34·85	0·266	1·00

Dr. H. Alt [1] has determined very carefully the latent heats of nitrogen (α) and oxygen (β) at many temperatures, and his results are given in column 8 of Table 57. The latent heat of mixtures of nitrogen and oxygen [2] was found by using the equation $C_a = n\alpha + o\beta$, in which α was assumed to vary between 44·01 and 47·64 kg. cal. and β between 50·7 and 53·51 kg. cal., in accordance with the temperature of the vapour. Although these values are small and do not change appreciably within the narrow temperature-range of the boiling-points (77–90° abs., — 196° to — 183° C.), their fluctuations have been considered as a matter of principle. This could not be done in the case of the liquid mixtures previously considered, owing to lack of exact knowledge of the physical constants concerned.

In columns 3, 4, 5 of the first part of Table 58 are given the theoretical reflux-heat requirements for producing 10 kg. of nitrogen, as gas containing 95, 98, 99 per cent., from liquid mixtures with contents of 10–80 per cent. (90–20 per cent. oxygen); these were calculated from the equation

$$C_R = \frac{n(f_m - f_e)(\alpha + f_M\beta)}{f_M - f_m}.$$

[1] H. Alt, *Abhand. Kgl. Bayer. Akad. Wiss.*, 1905–6, **22**, Abt. III, 527.
[2] The author is indebted to Dr. Alt for valuable communications on this subject.

It will be remarked that the reflux-heat requirement is not affected to any extent by the purity (*i.e.*, freedom from oxygen) of the nitrogen produced; but it increases regularly with diminishing content of nitrogen in the original liquid.

The second part of Table 58 shows the heat required in boiling-columns to separate the oxygen from liquid mixtures containing 1·9–80 per cent. of nitrogen, the liquid run off from the column consisting of oxygen (100 kg.) contaminated with 0·3 per cent. of nitrogen. In comparison with other mixtures, the heat required to separate the constituents of air is small.

The information given by this table leads naturally to a consideration of the number of plates to be used in the columns. The results of the calculations relating to this are recorded in Tables 59 and 60, the former of which gives, for five different rectifying columns, the percentage of nitrogen in the liquid and vapour on each plate, the reflux-heat requirements for 10 kg. of 99·5 per cent. nitrogen varying from 800 to 2500 kg. cal. Nine plates are usually sufficient, but the minimal content of nitrogen in the original mixture must not be lower than 10·25–28·8 per cent., according to the amount of heat expended.

Table 60 applies to boiling-columns; it gives the nitrogen-content of liquid and vapour on each of nine plates when mixtures containing 76·69–92·19 per cent. of nitrogen are distilled with a total heat-expenditure of 25,000–85,000 kg. cal. for every 100 kg. of oxygen (99·7 per cent.) separated. As the air contains 23·1 per cent. oxygen and 76·9 per cent. nitrogen, 4–6 plates are needed theoretically to free this liquid mixture from nitrogen at the normal boiling-point of liquid air, the heat-expenditure being that needed to separate 100 kg. of oxygen. The method of calculating these tables has already been explained.

The familiar equation given below is used for ascertaining the heat to be applied in, or taken from, a continuous-distillation apparatus in order to produce from 100 kg. of liquid air at its normal boiling-temperature a mixture of 76·83 kg. nitrogen containing 0·38 kg. oxygen (99·5 per cent. nitrogen), and 22·720 kg. oxygen containing 0·071 kg. of nitrogen (99·7 per cent. oxygen).

$$C_a = C_e + C_R + C_h = \frac{n(f - f_e)(\alpha + f_m\beta)}{f_M - f_m}$$

where $C_h = 0$ and $f = f_M$, because the liquid air enters the apparatus at its boiling-temperature.

Inglis [1] has also determined the nitrogen-content of the vapours evolved from nitrogen-oxygen solutions at constant temperatures, viz., 79·07° and 74·7° abs., the pressure of the oxygen being 200 and 100 mm. respectively. This author states his results as molecular percentages, and these are reproduced in the following table as percentages by weight, together with the partial pressures of the component gases. Unfortunately, these experimental results cannot be used for our present purposes.

Mol. per cent.		Wt. per cent.		Partial pressures.	
N Liquid.	N Vapour.	N Liquid.	N Vapour.	N mm.	O mm.
Temp. 79·07° abs. (— 193·93° C.)			Pressure of oxygen = 200 mm.		
0	0	0	0	0	200
3·4	16·7	2·98	21·9	37	194·5
10·7	39·2	9·40	36·1	114·3	181·2
19·7	55·5	17·90	52·1	205·8	165·7
27·8	65·4	25·15	62·3	284·8	150·7
40·5	75·8	37·25	72·9	402·2	127·8
51·0	82·1	47·48	81·1	495·5	108·5
60·4	86·4	57·50	84·7	577·6	89·4
72·8	91·5	70·20	92·2	684·7	65·3
82·8	94·8	81·0	94·1	773·6	42·4
90·8	97·6	88·96	97·0	845·6	24·4
99·7	99·7	99·5	99·5	928·0	0·50
100	100	100	100	931·0	0
Temp. 74·7° abs. (— 198·3° C.)			Pressure of oxygen = 100 mm.		
0	0	0	0	0	100
5·3	25·5	4·67	22·84	34·5	95·5
21·0	61·4	18·87	58·23	129·5	81·0
41·8	80·0	25·41	77·70	242·0	61·7
63·1	89·2	60·0	87·90	347·9	42·1
99·4	99·9	99·20	99·80	528·5	0·5
100	100	100	100	531·0	0

A few observations by Inglis, recorded elsewhere, on the vaporisation of liquid mixtures of argon and oxygen at constant temperature (82·09° abs., — 190·91° C.) are given here.

Mol. per cent. *A* in liquid	0	3·30	5·6	10·2	13·6	92·7%
,, ,, ,, vapour	0	5·76	9·15	16·0	20·6	97·8%
Wt. per cent. *A* in liquid	0	7·83	12·89	22·09	28·21	96·8%
,, ,, ,, vapour	0	11·199	20·25	32·18	39·28	99·9%
Partial pressure *A*, mm.	0	17·0	28·5	51·4	67·5	
,, ,, O, mm.	300	290·5	283·5	269·8	260·0	

[1] J. K. H. Inglis, *Proc. Phys. Soc. London*, 1906, **20**, 152.

31. NITROGEN AND ARGON

The physical constants of these gases were given in a table in the preceding section.

The vapour-composition curve for nitrogen–argon mixtures was published by Holst and Hamburger;[1] the values given in percentages by volume have been converted into percentages by weight and interpolated with the aid of the equation

$$\log f = a + b \log f_d \quad . \quad . \quad . \quad . \quad . \quad (200)$$

in which f and f_d are the ratios, $a = 0{\cdot}496$ and $b = 1{\cdot}06$ at 760 mm., and by means of a curve. The results of the calculation are given in Table 61 and in Chart XVI.

If v_n, v_a represent the volumes of the gases in a mixture, γ_n and γ_a their densities, then the percentages by weight can be calculated from the percentages by volume by the equation

$$p_n = \frac{100}{1 + \left(\frac{100}{v_n} - 1\right)\frac{\gamma_a}{\gamma_n}}.$$

The latent heat of argon is stated by Crommelin[2] to be 35–47 kg. cal. This is probably a calculated value; the correct value is, apparently, unknown; in our calculations we have taken $\beta = 40$ kg. cal. per kg.

Table 62 gives the heat-consumption in rectifying and boiling-columns; Tables 63 and 64 the nitrogen-content on the plates. On account of the small proportion of argon in the air, the heat required for its separation in a pure state is considerable.

32. WATER AND NITRIC ACID

The specific gravity of anhydrous nitric acid (HNO_3) is 1·530; its boiling-point is 86° C., and that of the 68 per cent. acid 120·1° [under 735 mm. (Roscoe)].

Between 21° and 52° C., acid containing 2·5 per cent. of water has the specific heat 0·6551, acid with 25 per cent. water 0·8752.

[1] G. Holst and L. Hamburger, *Z. physikal. Chem.*, 1916, **91**, 513.

[2] C. A. Crommelin, Communication from the Physical Laboratory of Leyden, No. 140*a*, "New Determination of the Vapour-pressure of Solid Argon down to − 205° C."

The molecular weight is 63·05, and the latent heat of vaporisation at 86° is 115·1 (Berthelot).

As no experimental results concerning the composition of the vapours evolved from mixtures of water and nitric acid could be found in the literature, Dr. Boll, acting on the author's suggestion, made some determinations, and his results are given in Table 65 and in Chart XV. They confirm the statement that mixtures containing approximately 32 per cent. water and 68 per cent. nitric acid give vapours of identical composition, and that, after repeated distillation, the composition of all mixtures stronger or weaker than this approaches that just given. From mixtures containing 32 per cent. or more of water, water distils off first, and therefore it is made the basis of the calculations.

Tables 66–68 show that much heat is needed to separate water from aqueous acid in rectifying columns, and that still more is required for the same purpose in boiling-columns from which the separated acid is run off at the base. For example, to produce 100 kg. of 68 per cent. acid hardly less than 1 million kg. cal. must be used.

33. CALCULATION OF THE VAPOUR-COMPOSITION CURVE

The vapour–composition curve of a binary liquid mixture shows the relation between the percentages by weight of the low-boiling component in the liquid (represented by the abscissæ) and the percentages of it in the vapour (represented by the ordinates) (*cf.* Charts III, XV, XVI). Knowledge of this curve is essential for determining data relating to apparatus used for separating such mixtures. A number of vapour-composition curves has been determined by direct experiment and most of them (representing the work of but few investigators) are considered in these pages; the available material is, however, not extensive.

In this connection Dolezalek [1] has formulated the following law relating to binary solutions, which is of general validity: *The partial pressure of a component of a vapour-mixture is equal*

[1] F. Dolezalek, *Z. physikal. Chem.*, 1908, **64**, 727; 1910, **71**, 137, 191; 1913, **83**, 40. F. Dolezalek and A. Schulze, *ibid.*, 1913, **83**, 45. H. G. Möller, *ibid.*, 1909, **69**, 449. A. Schulze and H. Hock, *ibid.*, 1914, **86**, 445. A. Schulze, *ibid.*, 1914, **86**, 309. The author desires to acknowledge his great indebtedness to Prof. Dr. Dolezalek for much information concerning the relations between solutions and their vapours.

to the saturation pressure of the pure component multiplied by its molar concentration in the liquid mixture. With the aid of this generalisation, it is possible to calculate a vapour-composition curve, if the component pressures and the total pressure are known for several temperatures.

The degree of simplicity of the calculation depends upon whether the liquid mixture and the vapour from it contain only simple molecules, or if one of the two liquids forms aggregates of two or three molecules; or, again, if the two components unite to form a chemical compound. In the first case the calculation is very simple; in the other cases it is much more complicated. Our knowledge concerning solutions containing more than two liquids is scanty and insufficient to be used in technical calculation.

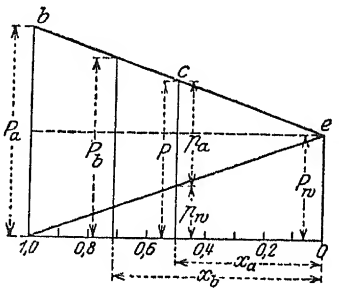


FIG. 14.

Once the relationship between the partial pressures has been calculated by Dolezalek's method, the further step of determining the ratio of the weights of the components in the vapour-mixture is easy, because by Avogadro's rule equal volumes of all gases, at the same temperature and pressure, contain an equal number of molecules. Since the pressure is proportional to the number of molecules, it follows that the ratio of the partial pressures is the same as the ratio of the proportions by weight.

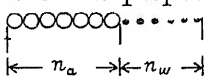
A. If only simple molecules  are present the total vapour-pressure (*i.e.*, the sum of the partial pressures of the components) of a liquid mixture lies between the saturation pressures of its components, and the partial pressures of these have the same relation to their saturation pressures as the molar proportions have to the total number of mols in the solution, the temperature remaining constant.

Fig. 14 shows the relations between the vapour pressures and the compositions of the solution. P_a and P_w represent the vapour-pressures of the pure liquids a and w; the subdivisions of the line 0–1 give the molecular proportion of the component a in the liquid mixture; the straight line b, c, e defines the total pressures of all mixtures of the two components, the temperature remaining constant. If P_a and P_w are known, the total pressure P corresponding to any mixing proportion of the liquids can at once be found from this figure.

Similarly, if only one component pressure (say, P_w) and the total pressure (P_b) of a given solution are known, the other component pressure (P_a) can be calculated:

$$P - P_w : P_a - P_w = x_a : 1 \quad . \quad . \quad . \quad . \quad (201)$$

$$P = (P_a - P_w)x_a + P_w$$

$$\mathbf{x_a = \frac{P - P_w}{P_a - P_w}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (202)$$

$$\left[\begin{array}{l} P - P_w : P_b - P_w = x_a : x_b \\ P = \dfrac{(P_b - P_w)x_a + P_w \,.\, x_b}{x_b} \\ x_a = \dfrac{(P - P_w)x_b}{P_b - P_w} \end{array}\right]$$

$$\left[\begin{array}{l} P_b - P_w : P_a - P_w = x_b : 1 \\ P_a = \dfrac{(P_b - P_w) + P_w x_b}{x_b} \end{array}\right] \quad . \quad . \quad . \quad (203)$$

Equation (202) is to be used for ascertaining the composition of the solution x_a when the total pressure P (say, atmospheric pressure) and the component pressures, P_a and P_w, are known.

Fig. 14 can also be used for finding the partial pressures (p_a and p_w) of the component gases in the vapour-mixture when P_a and P_w are known:

$$p_a = P_a x_a \qquad p_w = P_w(1 - x_a) = (P - p_a)$$

$$\mathbf{p_a = \frac{P_a(P - P_w)}{P_a - P_w}} \qquad p_w = P_w\left(1 - \frac{P - P_w}{P_a - P_w}\right) \quad . \quad . \quad (204)$$

[or, if only P_w, P_b, and x_b are known

$$p_a = P - P_w + P_w x_a = P - P_w + P_w \frac{(P - P_w)x_b}{P_b - P_w}\Bigg] \quad . \quad . \quad (205)$$

From the values of the partial pressure p_a and the molar proportion x_a found in this way, the percentage by weight of the low-boiling component in the solution (A%) can be deduced. If m_a and m_w are the molecular weights of the components a and w

$$A\% = \frac{x_a m_a 100}{m_w} = \frac{p_a m_a 100}{P_a m_w} = \frac{(P - P_w) m_a 100}{(P_a - P_w) m_w} \quad . \quad . \quad (206)$$

If we know the individual pressures of both the liquid components of a solution at a number of temperatures t_1, t_2 . . ., we can draw a series of diagrams like Fig. 15 for any given temperature.

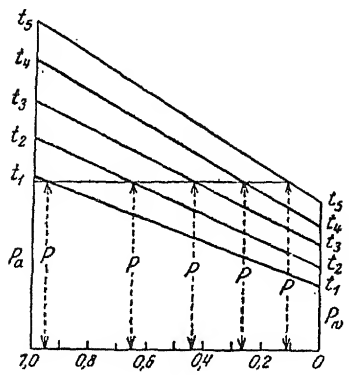


Fig. 15.

If at a distance P (representing, say, atmospheric pressure) we draw a line parallel to the horizontal axis, then points where perpendiculars drawn from the points of intersection of this line and the lines t_1t_1, t_2t_2 . . . cut the axis of abscissæ, represent the molar proportions of the components in the solutions at the given temperatures.

If we employ an axis of temperature, normal to the axes shown in Fig. 15, we obtain a spatial representation of the vapour-pressures corresponding to all mixing proportions, namely, a curved surface *bbee* in which the line *hik* joins up the extremities of the ordinates representing the same total pressure for different temperatures and compositions of the solution. Another common total pressure would be represented by another line, and so on.

In Fig. 16, the ordinates of points on the curves *bb*, *ee* represent the individual (saturation) pressures, P_a and P_w, of the components a and w, and the abscissæ represent the temperatures 0–100°, and the composition ratios of the solution. The extremities of the ordinates for equal temperatures are joined up by the straight lines *be*. The extremities of all ordinates corresponding to abscissæ representing equal molecular proportions but different temperatures lie on the lines *fg*. On each of these lines there is a point, of which one ordinate represents the same total pressure P. By joining such points we obtain the curved line *hik*. All perpendiculars dropped from this line on to the base of the diagram a,0,100,100 are equal (P) and

the respective abscissæ along 0,1·0 represent the molar proportions (*i.e.*, the proportions by weight in the solution) and, along 0,100, the boiling-temperatures under pressure P.

After determining in this way the partial pressures p_a and p_w of the vapours evolved from various mixtures of the two liquids a and w, the percentage weights $a\%$ and $b\%$ of the component substances in the vapour can be found as follows.

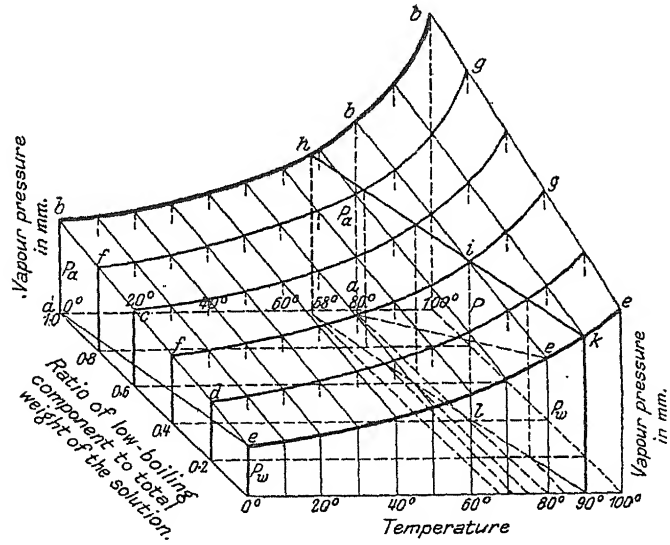


FIG. 16.

If m_a and m_w represent the molecular weights, n_a and n_w the numbers of the molecules in the vapour, g_a and g_w the densities, then

$$\frac{p_a}{P} = \frac{n_a}{n_a + n_w} = \frac{\dfrac{g_a}{m_a}}{\dfrac{g_a}{m_a} + \dfrac{g_w}{m_w}} = \frac{1}{1 + \dfrac{m_a g_w}{m_w g_a}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (207)$$

$$a\% = \frac{g_a 100}{g_a + g_w}\,;\; g_a = \frac{a\%(g_a + g_w)}{100}\,;\; g_w = \frac{w\%(g_a + g_w)}{100} \quad . \quad (208)$$

$$\frac{p_a}{P} = \frac{1}{1 + \dfrac{m_a w\%}{m_w a\%}} = \frac{1}{1 + \dfrac{m_a}{m_w}\left(\dfrac{100}{a\%} - 1\right)} \quad . \quad . \quad . \quad . \quad . \quad . \quad (209)$$

$$a\% = \frac{100}{\left(\dfrac{P}{p_a} - 1\right)\dfrac{m_w}{m_a} + 1} \qquad w\% = 100 - a\% \quad . \quad . \quad . \quad . \quad (210)$$

x_a is calculated from equation (202), and p_a from equation (204).

Examples.—The three following examples have been calculated by the method just described. They give the content of low-boiling component of liquid and vapour of three different binary mixtures. The corresponding vapour-composition curves are given in Fig. 17. They apply to atmospheric pressure ($P = 760$).

a = Chlorobenzene [1] (C_6H_5Cl). $m_a = 112{\cdot}5$

w = Bromobenzene (C_6H_5Br). $m_w = 157$ $\quad \frac{m_w}{m_a} = 1{\cdot}395$

Temp. °C.	Individual pressures		% wt. of a in the solution $A\% = x_a \frac{m_a}{m_w} 100$	Partial pressure of a at 760 mm. $p_a = P_a x$	Value of denominator $\left(\frac{760}{p_a} - 1\right)\frac{m_w}{m_a} + 1$	% wt. of a in vapour
	P_a mm.	P_w mm.				
135	800	390	64·68	721·6	1·0722	92·5
140	938·8	496·75	42·80	599·9	1·489	67·15
145	1000	550	29·46	435·6	2·028	49·31
150	1207	651	14·05	235·5	4·080	24·50
155	1367	750	1·161	22·1	47·60	2·104

a = Ethylene dibromide [2] ($C_2H_4Br_2$). $m_a = 188$

w = [illegible] (αβ-dibromopropane) [3] ($CH_3CHBrCH_2Br$).

$m_w = 202$ $\quad \frac{m_w}{m_a} = 1{\cdot}074$

135	825	86	84·33	749·9	1·010	98
140	953	87	71·88	736·6	1·0331	96·7
145	1090	88	62·49	732	1·0438	95·7
150	1233·8	89	54·70	723·5	1·0481	95·5
155	1403·6	89·5	47·52	719	1·0513	94·3
160	1573·5	90	42·03	709	1·0759	93

a = Benzene [2] (C_6H_6). $m_a = 78{\cdot}1$

w = Chlorobenzene [1] (C_6H_5Cl). $m_w = 112{\cdot}5$ $\quad \frac{m_w}{m_a} = 1{\cdot}428$

85	880	175	57·68	730·4	1·057	94·7
90	1012·75	208·3	49	698	1·123	88·6
95	1180	250	38·01	645	1·253	79·9
100	1340	292·7	31·03	597	1·393	71·9
105	1542	345	24·08	537	1·583	63·29
110	1744	403·7	18·49	462·8	1·912	52·3
115	1989	543	13·13	376	2·450	40·81
120	2235	543	8·89	287	3·345	29·9
125	2537	680	2·995	109·2	9·50	10·19
130	2824	720	1·313	53·2	13·28	4·975

NOTE.—The figures in columns 2 and 3 are taken from: [1] S. Young (calculated values), *J. Chem. Soc.*, 1889, **55**, 486 [Kahlbaum, *Z. physikal. Chem.*, 1898, **26**, 600, gives values for higher pressures]. [2] Regnault. [3] G. W. A. Kahlbaum, *Z. physikal. Chem.*, 1898, **26**, 626.

B. We have now to consider the case in which one or both of the liquids composing the mixture contain not only single

molecules, but double or triple molecules, *i.e.*, molecular association takes place. When this occurs in the solution, it also occurs, although usually to a much smaller extent, in the vapour evolved from it. The calculation of the pressures of the components of such mixtures was first rendered possible when Dolezalek enunciated his Law of Partial Pressures: for when the partial pressures are known, the relative proportions by weight of the

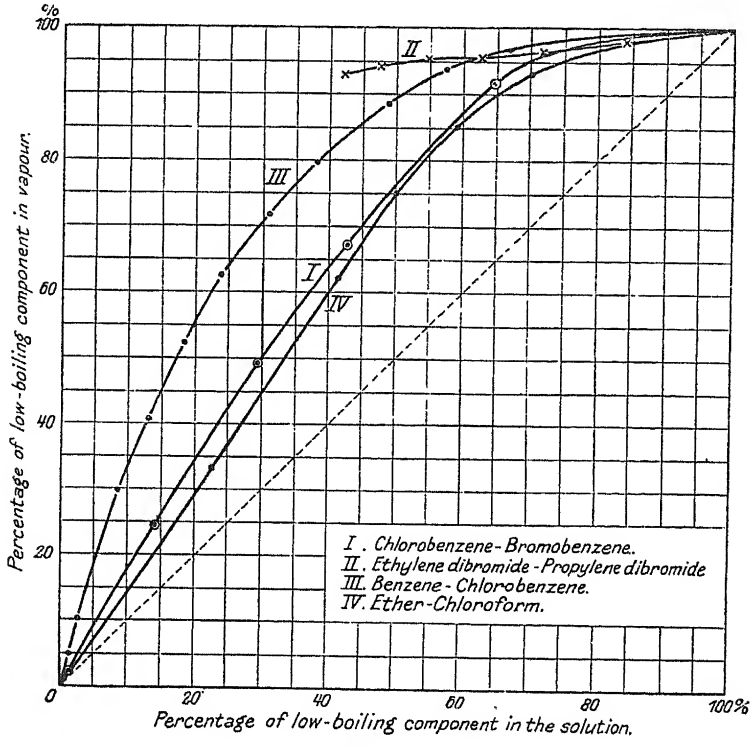
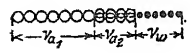


FIG. 17.

components in the vapour can be found. Nevertheless, in spite of the great simplicity of the Law, the actual calculation is always more complicated than for the case in which single molecules only are present. We have now to consider the two cases. Common to both is the fact that the number of double molecules in a liquid usually diminishes with rising temperature, whilst the number present in a vapour diminishes as the pressure falls. Therefore, when a liquid containing polymerised molecules is gradually heated, at first it contains many, but the vapour

very few, double molecules; as the temperature and pressure rise, dissociation occurs in the liquid, but further polymerisation may take place in the vapour.

C. *If one of the two component liquids forms double molecules*



(Fig. 18). If, at a given temperature, only simple molecules are present, the liquids a and w give vapours whose pressures are represented by ab' and eo, and the vertical lines representing the total vapour-pressures of all mixtures of them terminate on the straight line $b'c'e$. But if the liquid a contains double molecules as well as single, the number of the latter must be smaller, and since the vapour-pressure depends

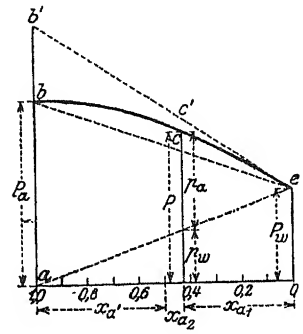


FIG. 18.

mainly upon these, the vapour-pressure is also smaller, and hence in the diagram it is represented by the straight line extending only from a to b. If the ratio of the number of double molecules to that of single molecules in liquid a remains the same, even when it is mixed with w, then the total vapour-pressures of the mixtures are represented by lines lying proportionally between ab and eo and terminating on the line $bc''e$. But the number of double molecules does not remain the same, even if the temperature remains constant; it diminishes, because the double molecules dissociate more and more as the liquid a is diluted with the liquid w, *i.e.*, as the molecules of a are thrust further and further apart by the intervening molecules of w. Then, owing to this increase in the number of its molecules, a also increases in pressure; but at the same time its pressure is reduced because, owing to dilution with w, its relative amount diminishes, whilst the amount and vapour-pressure of w increase. In this way

we see that a line, such as *bce*, represents values of the total pressures. If both liquids form double molecules, the point *e* is depressed and the line of total pressure lies below *bce*. The total vapour-pressure of every mixture of *a* and *w* is made up of the pressure due to the single molecules of *a*, that due to the double molecules of *a*, and that due to the single molecules of *w*.

Exactly as in Fig. 16, we can construct a three-dimensional diagram of the pressures corresponding to mixtures of varying composition. This is given in Fig. 19.

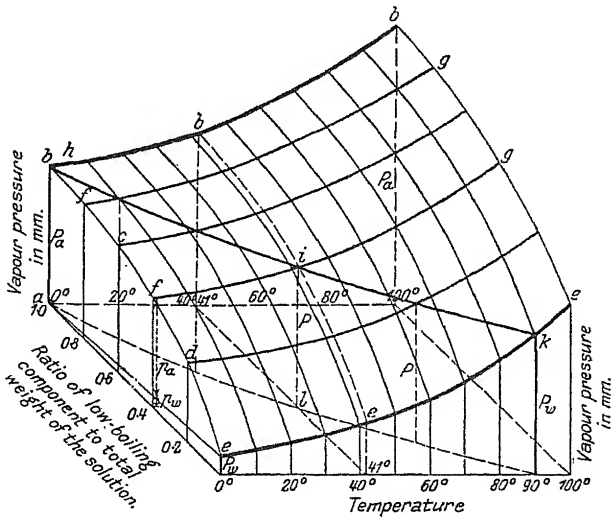


FIG. 19.

The proportion by weight in which each of the individual substances is present in the mixture can be expressed in two ways: (1) by the ratio of the number of molecules n_a and n_w to the total number of molecules $n_a + n_w$, on the assumption that only single molecules are present, that is, by the molar fractions

$$q_a = \frac{n_a}{n_a + n_w} \text{ and } q_w = \frac{n_w}{n_a + n_w}.$$

Dolezalek calls these the "analytical molar fractions" because they are found by analysing the mixture. These molar fractions are obtainable directly from the known weights of the components in the mixture g_a, g_w, and their molecular weights m_a, m_w.

(2) The second way of subdividing the total weight of the

mixture is to treat separately the molar fractions of the simple and the double molecules. These are called by Dolezalek the "true molar fractions." If ν_w be the number of single molecules of w, ν_{a_1} that of the single molecules of a, and ν_{a_2} that of the double molecules of a, then the true molar fractions are

$$\left.\begin{aligned} x_w &= \frac{\nu_w}{\nu_w + \nu_{a_1} + \nu_{a_2}} = \frac{\nu_w}{B} & \nu_w &= x_w B \\ x_{a_1} &= \frac{\nu_{a_1}}{\nu_w + \nu_{a_1} + \nu_{a_2}} = \frac{\nu_{a_1}}{B} & \nu_{a_1} &= x_{a_1} B \\ x_{a_2} &= \frac{\nu_{a_2}}{\nu_w + \nu_{a_1} + \nu_{a_2}} = \frac{\nu_{a_2}}{B} & \nu_{a_2} &= x_{a_2} B \end{aligned}\right\} \quad . \quad . \quad (211)$$

The sum of the true molar fractions must be equal to that of the analytical, *i.e.*, equal to the whole mixture, which we may put = 1

$$(q_a + q_w = x_{a_1} + x_{a_2} + x_w = 1).$$

If we wish to calculate the proportions by weight in which the substances are present in the mixture, the true molar fractions, x_{a_1}, x_{a_2}, x_w must be expressed in terms of the analytical molar fractions q_a, q_w. The double molecules ν_{a_2} have twice the weight of the single; hence

$$\left.\begin{aligned} q_a &= \frac{\nu_{a_1} + 2\nu_{a_2}}{\nu_{a_1} + 2\nu_{a_2} + \nu_w} \\ q_w &= \frac{\nu_w}{\nu_{a_1} + 2\nu_{a_2} + \nu_w} \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (212)$$

If we replace $\nu_w + \nu_{a_1} + \nu_{a_2}$ by B, then by equation (211)

$$q_a = \frac{x_{a_1}B + 2x_{a_2}B}{x_{a_1}B + 2x_{a_2}B + x_w B} = \frac{x_{a_1} + 2x_{a_2}}{x_{a_1} + 2x_{a_2} + x_w} = \frac{x_{a_1} + 2x_{a_2}}{1 + x_{a_2}},$$

since $x_{a_1} + x_{a_2} + x_w = 1$.

$$q_w = \frac{x_w}{1 + x_{a_2}} \qquad x_{a_2} = \frac{x_w - q_w}{q_w} \quad . \quad . \quad . \quad (213)$$

Since $q_a = \dfrac{x_{a_1} + 2x_{a_2}}{1 + x_{a_2}}$ and $q_a = 1 - q_w$

$$\begin{aligned} x_{a_1} &= q_a + q_a x_{a_2} - 2x_{a_2} = q_a\left(1 + \frac{x_w - q_w}{q_w}\right) - 2\frac{x_w - q_w}{q_w} \\ &= \frac{q_w - q^2_w + x_w - x_w q_w - q_w + q^2_w - 2x_w + 2q_w}{q_w} \\ &= \frac{2q_w - x_w(1 + q_w)}{q_w} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (214) \end{aligned}$$

In order to calculate the number of simple molecules in component a, we must first know the value of the constant K characterising the Law of Mass Action; in this case

$$K = \frac{X_{a_2}}{X^2_{a_1}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (215)$$

The total pressure above the solution P is the sum of the partial pressures p_{a_1}, p_{a_2}, p_w, and, according to Dolezalek's law, the partial pressures are equal to the products of the pressures of the pure substances and the true molar fractions

$$p_{a_1} = P_{a_1}x_{a_1}, \quad p_{a_2} = P_{a_2}x_{a_2}, \quad p_w = P_w x_w$$
$$P = P_{a_1}x_{a_1} + P_{a_2}x_{a_2} + P_w x_w \quad . \quad . \quad . \quad . \quad . \quad (216)$$

In the last equation P_{a_1} represents the pressure of the single molecules of the pure substance, not the pressure of the pure substance itself; its value can be determined, by applying the Law of Mass Action, from the pressure of the double molecules P_{a_2} and the total pressure of the pure component a, *i.e.*, P_a.

If $x^1_{a_1}$ represents the true molar fractions of the simple molecules, and $x^1_{a_2}$ those of the double molecules, then the constant is given by the equation

$$K = \frac{X^1_{a_2}}{X^{1^2}_{a_1}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (217)$$

Further, $$P_a = P_{a_1}x_{a_1} + P_{a_2}x_{a_2} \quad . \quad . \quad . \quad . \quad (218)$$
and lastly, $$x_{a_1} + x_{a_2} = 1$$

Now P_{a_1} has to be expressed in terms of P_a and P_{a_2}, and to do this we proceed as follows:

First, we substitute K for the molar fractions, using equation (215).

$$x^2_{a_1} \,.\, K = x_{a_2} = 1 - x_{a_1}.$$

Solving this quadratic equation we obtain

$$x_{a_1} = \frac{\sqrt{4K+1} - 1}{2K}, \quad x_{a_2} = 1 - x_{a_1} \quad . \quad . \quad . \quad . \quad . \quad (219)$$

Equation (218) may now be written in the form

$$P_{a_1} = \frac{P_a - P_{a_2} \,.\, x_{a_2}}{x_{a_1}} \text{ and since } x_{a_1} + x_{a_2} = 1$$

$$P_{a_1} = \frac{P_a(x_{a_1} + x_{a_2}) - P_{a_2}x_{a_2}}{x_{a_1}}; \quad x_{a_2} = Kx^2_{a_1}$$

$$= P_a + P_a \,.\, \frac{K \,.\, x^2_{a_1}}{x_{a_1}} - \frac{P_{a_2} \,.\, x^2_{a_1} \,.\, K}{x_{a_1}}$$

$$= P_a + P_a \,.\, Kx_{a_1} - P_{a_2}x_{a_1} \,.\, K.$$

Substituting for $x_{a_1}K$ the value found from equation (219) we obtain,

$$P_{a_1} = P_a + P_a\frac{\sqrt{4K+1}-1}{2} - \frac{P_{a_2}(\sqrt{4K+1}-1)}{2}$$

$$P_{a_1} = 0{\cdot}5[P_a(\sqrt{4K+1}+1) - P_{a_2}(\sqrt{4K+1}-1)]$$

$$\mathbf{P_{a_1} = 0\ 5[P_a + P_{a_2} + (P_a - P_{a_2})\sqrt{4K+1}]} \quad . \quad . \quad . \quad . \quad (219\,a)$$

P_{a_2}, being very small, may be neglected, hence

$$P_{a_1} = 0{\cdot}5P_a(1+\sqrt{4K+1}) \quad . \quad . \quad . \quad (220)$$

On squaring this equation we obtain

$$\mathbf{P_{a_1}{}^2 - P_{a_1}P_a = KP_a{}^2} \quad . \quad . \quad . \quad . \quad . \quad (221)$$

Further, we may express the true molar fractions of the associated liquid a in terms of the analytical molar fractions of the unassociated liquid w.

If the mixture contains x_w gram-molecules of the component w, it also contains x_{a_1} single gram-molecules and x_{a_2} double gram-molecules of the associated component a, and the double molecules naturally have twice the weight of the single molecules.

Hence $$q_w = \frac{x_w}{x_w + x_{a_1} + 2x_{a_2}}$$

Now since $x_w + x_{a_1} + x_{a_2} = 1$, the last equation assumes the simpler form

$$q_w = \frac{x_w}{1 + x_{a_2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (222)$$

Since $q_a + q_w = 1$, it follows that

$$q_a = (1 - q_w) = \frac{(1 + x_{a_2}) - x_w}{1 + x_{a_2}} = \frac{(1 + x_{a_2}) - (1 - x_{a_1} - x_{a_2})}{1 + x_{a_2}}$$

$$q_a = \frac{x_{a_1} + 2x_{a_2}}{1 + x_{a_2}} \quad . \quad . \quad . \quad . \quad . \quad (223)$$

From equation (222) it at once follows that

$$\mathbf{x_{a_2} = \frac{x_w - q_w}{q_w}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (224)$$

From equation (223)

$$(1 - q_w)(1 + x_{a_2}) = x_{a_1} + 2x_{a_2}$$

Inserting in this equation the value of x_{a_2} found in equation (224) and completing the calculation we find

$$x_{a_1} = \frac{2q_w - x_w(q_w + 1)}{q_w} \quad . \quad . \quad . \quad . \quad (225)$$

K is now determined by inserting in equation (215) the values of x_{a_2} and x_{a_1} found in equations (224) (225).

$$K = \frac{(x_w - q_w)q_w^2}{q_w\{2q_w - x_w(1 + q_w)\}^2} =$$

$$\frac{(x_w - q_w)q_w}{\{2q_w - x_w(1 + q_w)\}^2} = \frac{(x_w - q_w)q_w}{D^2} \quad . \quad . \quad . \quad (226)$$

Equation (216), $P = P_{a_1}x_1 + P_{a_2}x_2 + P_w x_w$ is the analytical expression of Dolezalek's Law, and if in it we put $P_{a_2} = 0$ it follows that

$$P_{a_1} = \frac{P - P_w x_w}{x_{a_1}} = \frac{(P - P_w x_w)q_w}{2q_w - x_w(1 + q_w)} = \frac{(P - P_w x_w)q_w}{D} \quad . \quad (227)$$

We now take equation (221) and insert in it this value for P_{a_1} and the value of K given by equation (226). We obtain

$$P_{a_1}^2 - P_{a_1}P_a = \frac{(x_w - q_w)q_w P_a^2}{D^2}$$

Hence, $$\frac{(P - P_w x_w)^2 q_w^2}{D^2} - \frac{(P - P_w x_w)q_w P_a}{D} = \frac{(x_w - q_w)q_w \,.\, P_a^2}{D^2}$$

i.e., $$(P - P_w x_w)^2 q_w - (P - P_w x_w)D \,.\, P_a = (x_w - q_w)P_a^2$$

i.e., $$q_w P^2 - q_w 2PP_w x_w + P_w^2 x_w^2 q_w - PP_a D + P_w P_a x_w D = x_w P_a^2 - q_w P_a^2$$

i.e., $$q_w P^2 - q_w 2PP_w x_w + q_w P_w^2 x_w^2 - 2q_w PP_a + PP_a x_w(q_w + 1) + P_w P_a x_w 2q_w - P_w P_a x_w^2(q_w + 1) = x_w P_a^2 - q_w P^2$$

i.e., $$P^2 - 2PP_w x_w + P_w^2 x_w^2 - 2PP_a + PP_a x_w \frac{(q_w + 1)}{q_w} + P_w P_a x_w \frac{(2q_w - x_w)}{q_w} = \frac{x_w P_a^2}{q_w} - P_a^2 \quad . \quad . \quad (228)$$

If we now put

$$A = P^2 - 2PP_a + P_a^2$$

$$Bx_w^2 = x_w^2\left(P_w^2 - \frac{P_a P_w}{q_w}\right)$$

$$x_w C = x_w\left(2PP_w - PP_a\frac{q_w + 1}{q_w} + \frac{P_a^2}{q_w} - 2P_w P_a\right)$$

it follows at once that

$$x_w = \sqrt{\left(\frac{C}{2B}\right)^2 - \frac{A}{B}} + \frac{C}{2B} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (229)$$

We may now summarise the method to be used for finding the percentage by weight of a component (a) forming bi-molecular aggregates present, at a given temperature, in the vapour from a known solution ($q_a + q_w$) of total pressure (P): (a) x_w is found from equation (229); (b) x_{a_2} and x_{a_1} are found from equations (224) (225); (c) K is found from equation (215); (d) P_{a_1} and (since $P = P_w x_w + P_{a_1} x_{a_1}$) $P_w x_w$ are found from equation (220); (e) $a\%$ and $w\%$ are found by substituting in equation (210) P_{a_1} for p_a.

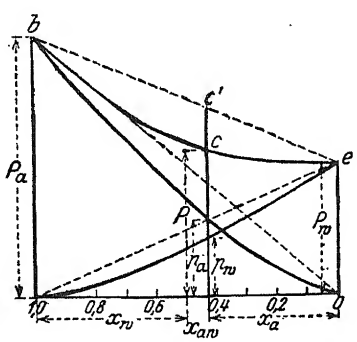
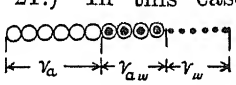


FIG. 20.

D. *The two liquids forming the mixture enter partially into chemical combination.*[1] (Figs. 20 and 21.) In this case the conditions resemble those just discussed 

. If, before mixing, the liquids contain only single molecules, their vapour pressures are represented by ab and eo; and if, on mixing, they do not interact chemically, the vapour from the mixture contains as many molecules as the two separate vapours together, and the lines representing the total pressures of mixtures (at constant temperature) must terminate on the straight line $bc'e$. If, however, certain molecules of a combine with a like number of molecules of b, one of each kind uniting to form one new molecule, the vapour-mixture will contain a few double molecules in place of a greater number of single molecules, and its pressure

[1] Chemical combination is usually indicated by a change of temperature on mixing the liquids.

will diminish; and this will reach a minimum when the number of molecules in it is equal to that present originally in a or w. The greater the number of molecules of a or w in the mixture, the more closely will the total pressure P approach the individual pressure of this component. Hence the line bce becomes concave, its lowest point lying in the middle. Fig. 21, which is analogous to Figs. 16 and 19, gives a spatial representation of the vapour pressure above solutions whose constituents enter into partial chemical combination.

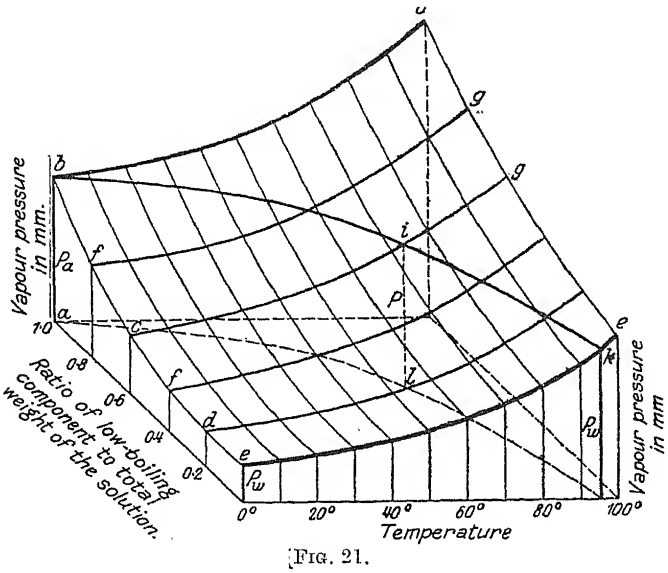


FIG. 21.

In this case also the analytical molar fractions are

$$q_a = \frac{n_a}{n_a + n_w}, \quad q_w = \frac{n_w}{n_a + n_w}, \text{ and } q_a + q_w = 1$$

and the true molar fractions, if ν_a, ν_{aw}, and ν_w be the numbers of the respective molecules, are given by

$$\left.\begin{aligned} x_a &= \frac{\nu_a}{\nu_a + \nu_{aw} + \nu_w}, & x_a &= \nu_a \\ x_{aw} &= \frac{\nu_{aw}}{\nu_a + \nu_{aw} + \nu_w}, & x_{aw} &= \nu_{aw} \\ x_w &= \frac{\nu_w}{\nu_a + \nu_{aw} + \nu_w}, & x_w &= \nu_w \end{aligned}\right\} \quad . \quad . \quad . \quad (231)$$

because $$x_a + x_{aw} + x_w = 1.$$

Further

$$\left.\begin{aligned} q_a &= \frac{\nu_a + \nu_{aw}}{(\nu_a + \nu_{aw}) + (\nu_w + \nu_{aw})} = \frac{\nu_a + \nu_{aw}}{1 + \nu_{aw}} = \frac{x_a + x_{aw}}{1 + x_{aw}} \\ q_w &= \frac{\nu_w + \nu_{aw}}{(\nu_a + \nu_{aw}) + (\nu_w + \nu_{aw})} = \frac{\nu_w + \nu_{aw}}{1 + \nu_{aw}} = \frac{x_w + x_{aw}}{1 + x_{aw}} \end{aligned}\right\} \quad . \quad . \quad (232)$$

because $\nu_a + \nu_{aw} + \nu_w = 1$.

Hence

$$\left.\begin{aligned} \mathrm{x_a} + \mathrm{x_{aw}} &= \mathrm{q_a} + \mathrm{q_a x_{aw}}, & \mathrm{x_a} &= \mathrm{q_a} - \mathrm{q_w x_{aw}} \\ \mathrm{x_w} + \mathrm{x_{aw}} &= \mathrm{q_w} + \mathrm{q_w x_{aw}}, & \mathrm{x_w} &= \mathrm{q_w} - \mathrm{q_a x_{aw}} \end{aligned}\right\} \quad . \quad . \quad . \quad (233)$$

To determine the ratio of the combined molecules to the uncombined, we again use the Law of Mass Action, the expression of which here takes the form

$$\mathrm{K} = \frac{\mathrm{x_{aw}}}{\mathrm{x_a x_w}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (234)$$

K representing the constant to be determined.

To find the value of K (corresponding to a definite temperature), we replace the true molar fractions in the equations by the total pressure P and the partial pressures p_a, p_w, p_{aw}.

By Dolezalek's Law the actual partial pressures are equal to the saturation pressures of the pure liquids (P_a, P_w) and of the pure mixture (P_{aw}) multiplied by the true molar fractions (x_a, x_w, x_{aw}); and the total pressure P is equal to the sum of the partial pressures :

$$p_a = P_a x_a, \quad p_w = P_w x_w, \quad p_{aw} = P_{aw} x_{aw},$$
$$P = P_a x_a + P_w x_w + P_{aw} x_{aw} \quad . \quad . \quad . \quad . \quad (235)$$

If we substitute the analytical molar fractions for the true molar fractions in equations (233), we obtain

$$P = P_a q_a - P_a \,.\, q_w \,.\, x_{aw} + P_w \,.\, q_w - P_w \,.\, q_a \,.\, x_{aw} + P_{aw} \,.\, x_{aw},$$
$$P = P_a \,.\, q_a + P_w \,.\, q_w + x_{aw}(P_{aw} - P_a q_w - P_w q_a),$$
$$x_{aw} = \frac{P_a q_a + P_w q_w - P}{P_w q_a + P_a q_w - P_{aw}} \quad . \quad . \quad . \quad . \quad (236)$$

From equations (233)

$$\frac{x_a - q_a}{q_w} = -x_{aw}, \qquad \frac{x_a - q_w}{q_a} = -x_{aw} \quad . \quad . \quad . \quad (237)$$

and therefore

$$x_a = q_a - \frac{q_w P_a q_a + q_w P_w q_w - q_w P}{P_w q_a + P_a q_w - P_{aw}} \quad . \quad . \quad . \quad (238)$$

Completing the calculation and using the relation $q_w = 1 - q_a$ we find

$$x_a = \frac{Pq_w - P_{aw}q_a + P_w(2q_a - 1)}{P_wq_a + P_aq_w - P_{aw}}$$

$$x_w = \frac{Pq_a - P_{aw}q_w + P_a(2q_w - 1)}{P_wq_a + P_aq_w - P_{aw}}$$

Substituting in equation (234)

$$\mathbf{K} = \frac{(\mathbf{P_aq_a + P_wq_w - P}).(\mathbf{P_wq_a + P_aq_w - P_{aw}})}{(\mathbf{P.q_w - P_{aw}q_a + P_w(2q_a - 1)}).((\mathbf{P.q_a - P_{aw}q_w + P_a(2q_w - 1)})} \quad (239)$$

In this equation P_a and P_w are the known saturation pressures of the component substances, P is the assumed total pressure for which the partial pressures (and ultimately the weight-proportions in the vapour-mixture) are calculated; q_a and q_w are the analytical molar fractions.

Having determined K, we can now find the true molar fraction x_{aw}.

According to equations (233) (234)

$$K = \frac{x_{aw}}{x_a \,.\, x_w} = \frac{x_{aw}}{(q_a - q_w x_{aw})(q_w - q_a x_{aw})} \quad . \quad . \quad . \quad (240)$$

$$\frac{K \,.\, q_a \,.\, q_w}{K \,.\, q_a \,.\, q_w} = \frac{K \,.\, q_w \,.\, q_w \,.\, x_{aw}}{K \,.\, q_a \,.\, q_w} + \frac{Kq_a \,.\, q_a \,.\, x_{aw}}{K \,.\, q_a \,.\, q_w} - x_a{}^2{}_w + \frac{x_{aw}}{Kq_aq_w}$$

$$x_a{}^2{}_w - x_{aw}\left(\frac{q_w}{q_a} + \frac{q_a}{q_w} + \frac{1}{K \,.\, q_aq_w}\right) = -1$$

$$x_{aw} = \frac{q_w}{2q_a} + \frac{q_a}{2q_w} + \frac{1}{2Kq_aq_w} - \sqrt{\left[\frac{q_w}{2q_a} + \frac{q_a}{2q_w} + \frac{1}{2Kq_a \,.\, q_w}\right]^2 - 1}$$

$$q_w{}^2 + q_a{}^2 = (q_a + q_w)^2 - 2q_aq_w = 1 - 2q_aq_w$$

$$x_{aw} = \left(\frac{q_a{}^2 + q_w{}^2}{2q_a \,.\, q_w} + \frac{1}{2Kq_aq_w}\right) - \sqrt{\frac{1}{(2Kq_aq_w)^2}[(1 - 2q_aq_w)K + 1]^2 - 1}$$

$$x_{aw} = \frac{1}{2Kq_aq_w}[(1 + K(1 - 2q_aq_w)) - \sqrt{(1 + K(1 - 2q_aq_w))^2 - (2Kq_aq_w)^2}]$$

$$x_{aw} = \frac{1}{2Kq_aq_w}[(1 + K(1 - 2q_aq_w)] - \sqrt{1 + 2K - 4q_aq_wK^2 + K^2 - 2K2q_aq_w + 4K^2q_a{}^2q_w{}^2 + 4K^2q_a{}^2q_w{}^2}$$

$$\mathbf{x_{aw} = \frac{1}{2Kq_aq_w}[(1 + K(1 - 2q_aq_w)) - \sqrt{(1 + K)\{1 + K(1 - 4q_aq_w)\}}]} \quad . \quad . \quad . \quad (241)$$

$$\mathbf{x_a = q_a - q_wx_{aw}}, \text{ (equation 233)}$$

$$\mathbf{x_w = q_w - q_ax_{aw}}$$

Determining in this way the true molar fractions of the liquid mixture (for a given temperature), the partial pressures of its vapour-constituents are found by multiplying these fractions by the saturation pressures of the pure liquids

$$p_a = P_a x_a \qquad p_w = P_w x_w \qquad p_{aw} = P_{aw} x_{aw}$$

$$P = p_a + p_w + p_{aw} = P_a x_a + P_w x_w + P_{aw} x_{aw} \quad . \quad . \quad . \quad (242)$$

Finally, equation (210) is used for determining the percentage composition of the vapour above the solution.

Example.—To determine the vapour-composition curve of solutions of ethyl ether and chloroform, the pressure being 760 mm. of mercury. Ethyl ether and chloroform enter partially into chemical combination.

The molecular weights are: ethyl ether $(C_2H_5)_2O = m_a = 74$.
chloroform $(CHCl_3) = m_c = 119{\cdot}4$.

The saturation pressures at various temperatures are given below; the values for 30°, 40°, 50°, 60°, are due to Regnault, the others have been calculated by the author:

	30°	35°	40°	45°	47·5°	50°	55°	60° C.
Ether . .	634·8	770	907	1080	1173	1265	1480	1725 mm.
Chloroform .	247·5	295	369	465	520	575	670	755 mm.

The value of K * for 33·25° C. is $K_1 = 2{\cdot}36$; for 60°, $K_2 = 1$; for intermediate temperatures T_1 and T_2 it can be calculated by means of van't Hoff's equation:

$$\frac{d \log nK}{dT} = -\frac{Q}{RT^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (243)$$

where T = absolute temperature, Q = heat of combination, R (the gas-constant) = 1·985.

Transforming and integrating this equation, we obtain

$$d \log nK = -\left(\frac{Q}{R}\right)\frac{dT}{T}$$

$$\Big[\log nK\Big]_{T_1}^{T_2} = -\frac{Q}{R}\int_{T_1}^{T_2}\frac{dT}{T^2} = \frac{Q}{R}\left[\frac{1}{T}\right]_{T_1}^{T_2}$$

$$\log nK_2 - \log nK_1 = -\left(\frac{Q}{R}\right)\left[\frac{1}{T_1} - \frac{1}{T_2}\right] = -\frac{Q(T_2 - T_1)}{RT_2 \,.\, T_1}$$

$$2{\cdot}303 \log K_2 - 2{\cdot}303 \log K_1 = -\left(\frac{Q}{R}\right)\frac{T_2 - T_1}{T_2 T_1} \quad . \quad (244)$$

$-\frac{Q}{R}$ can be found by inserting the known values of K_1, K_2, T_1, T_2, and then using $K_1 = 1$ at 60° ($\log 1 = 0$) we can find the still unknown values of K_2 for the range 33·25–60° C., which are required here, because the mixtures boil at 35–60° C. under atmospheric pressure.

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* F. Dolezalek, *Z. physikal. Chem.*, 1913, **83**, 54.

For $T_1 = 273 + 33{\cdot}25 = 306{\cdot}25°$ — $T_2 = 273 + 60 = 333°$ the value of $\frac{Q}{R}$ derived from equation (244) is 3274, and if this value be inserted in the same equation for $T_1 = 313°$, 318°, 320·5°, 323°, and 328°, we obtain the five respective values of K, namely $K_{40°} = 1{\cdot}894$, $K_{45°} = 1{\cdot}587$, $K_{47{\cdot}5°} = 1{\cdot}467$, $K_{50°} = 1{\cdot}353$, $K_{55°} = 1{\cdot}152$. Using these values in equation (239) for finding the analytical molar fractions q_a, q_w, we obtain the following expressions :

$$\text{at } 40° \quad 1{\cdot}894 = \frac{[907 \,.\, q_a + 369(1 - q_a) - 760] \,.\, [907(1 - q_a) + 369 \,.\, q_a]}{[760(1 - q_a) + 369(2q_a - 1)] \,.\, [760 \,.\, q_a + 907(2q_a - 1)]}$$

$$\text{,, } 45° \quad 1{\cdot}587 = \frac{[1080q_a + 465(1 - q_a) - 760] \,.\, [1080(1 - q_a) + 465q_a]}{[760(1 - q_a) + 465(2q_a - 1)] \,.\, [760q_a + 1080(2q_a - 1)]}$$

$$\text{,, } 47{\cdot}5° \quad 1{\cdot}467 = \frac{[1173q_a + 520(1 - q_a) - 760] \,.\, [1173(1 - q_a) + 520q_a]}{[760(1 - q_a) + 520(2q_a - 1)] \,.\, [760q_a + 1173(2q_a - 1)]}$$

$$\text{,, } 50° \quad 1{\cdot}355 = \frac{[1264{\cdot}8q_a + 575(1 - q_a) - 760] \,.\, [1080(1 - q_a) + 575 \,.\, q_a]}{[760(1 - q_a) + 575(2q_a - 1)] \,.\, [760 \,.\, q_a + 1264{\cdot}8(2q_a - 1)]}$$

$$\text{,, } 55° \quad 1{\cdot}152 = \frac{[1480q_a + 670(1 - q_a) - 760] \,.\, [1480(1 - q_a) + 670q_a]}{[760(1 - q_a) + 670(2q_a - 1)] \,.\, [760 \,.\, q_a + 1480(2q_a - 1)]}$$

On eliminating the value of q_a from each of these equations, we get three equations of the form :

$$\mathbf{a = bq_a + cq_a^2} \qquad \mathbf{q_a} = \sqrt{\frac{\mathbf{a}}{\mathbf{c}} + \left(\frac{\mathbf{b}}{\mathbf{2c}}\right)^2} - \frac{\mathbf{b}}{\mathbf{2c}} \qquad . \quad . \quad (245)$$

in which :

$$a = P_a(P_w - P_a)(1 + K)$$
$$b = P \,.\, P_w(1 - K) - P \,.\, P_a(1 + 3K) + P_a \,.\, P_w(2 + 4K) + P^2 - K - P_w^2 - P_a^2$$
$$c = P_a^2 + P_w^2 - P_aP_w(2 + 4K) + 2KP(P_a + P_w) - P^2$$

On inserting the numerical values

		40°	45°	47·5°	50°	55° C.
$P = 760$,	$P_a =$	907	1080	1173	1265	1480 mm.
	$P_w =$	369	465	590	575	670 ,,
	$K_{45-55} =$	1·894	1·587	1·467	1·355	1·152 ,,

we find for a, b, c the respective values

a_{40}	= − 1,024,500	b_{40}	= − 1,514,910	c_{40}	= + 341,310
a_{45}	= − 823,620	b_{45}	= − 1,205,725	c_{45}	= + 20,085
$a_{47{\cdot}5}$	= − 695,900	$b_{47{\cdot}5}$	= − 897,515	$c_{47{\cdot}5}$	= − 212,700
a_{50}	= − 550,000	b_{50}	= − 765,060	c_{50}	= − 450,475
a_{55}	= − 264,150	b_{55}	= − 546,469	c_{55}	= − 819,670

Inserting these values in equation (245),[1] we obtain

$q_a =$	0·823	0·700	0·620	0·531	0·321

These are the analytical molar fractions of ether in the mixture when $P = 760$ mm., and from them the corresponding percentage weights are found by means of the equation $A\ \% = \frac{q_a m_a 100}{q_a m_a + q_w m_w}$.

A % =	**70·29**	**59·05**	**50·03**	**41·27**	**22·70**

[1] For example, $q_{a40} = \sqrt{\frac{-0{\cdot}0245}{0{\cdot}341} + \left(\frac{-0{\cdot}515}{0{\cdot}682}\right)^2} - \frac{-0{\cdot}515}{0{\cdot}682} = 0{\cdot}823.$

The true molar fractions are obtained from equation (241) by inserting the values of K, P, P_a, P_w corresponding to the respective temperatures:[1]

x_{aw} =	0·114	0·200	0·203	0·204	0·130
x_a =	0·823	0·640	0·543	0·435	0·2328
x_w =	0·083	0·160	0·254	0·361	0·6373
	1·020	1·000	1·000	1·000	1·0001

The products of these values and the pressures P_a and P_w give the partial pressures p_a and p_w, whose sum $P = 760$. It is found that there is an error of 0·14–1·0%, which may be due to discarded decimals. Calculation shows that the mean differs from 760 mm. by not more than 0·274%.

p_a* =	728·3	691·2	636	550	344	mm.
p_w =	30·6	74·4	121·8	207·5	426·7	,,
P =	758·9	765·6	757·8	757·5	770·7	,,

The ether-content of the vapour, expressed as weight per cent., is given by the equation $a\,\% = \dfrac{p_a m_a 100}{p_a m_a + p_c m_c}$.

a % =	**93·2**	**85·3**	**76·5**	**62·2**	**33·3**

These values, together with those for A% given above, have been used to construct the vapour–composition curve IV given in Fig. 17.

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[1] For example,

$$x_{aw_{40}} = \frac{1}{2\,.\,0{\cdot}823\,.\,0{\cdot}177\,.\,1{\cdot}894}[(1 + 1{\cdot}894(1 - 2\,.\,0{\cdot}823\,.\,0{\cdot}177)) - \sqrt{(1 + 1{\cdot}894)[1 + 1{\cdot}894(1 - 4.0{\cdot}823\,.\,0{\cdot}177)]} = 0{\cdot}114.$$

* For example, $\left.\begin{array}{r} 0{\cdot}803\,.\,907 = 728{\cdot}3 \\ 0{\cdot}083\,.\,369 = 30{\cdot}6 \end{array}\right\} = 758{\cdot}9$ mm.

PART III

TABLES

TABLE I

Comparison of the values (T) found by D. Tyrer for the latent
the values (H) calculated from

Carbon Tetrachloride and Ether.					Chloroform and Benzene.			
CCl_4 in liquid wt. %	CCl_4 in vapour wt. %	Latent heat T kg. cal.	Latent heat H kg. cal.	Boiling-temp. °C.	$CHCl_3$ in vapour wt. %	Latent heat T kg. cal.	Latent heat H kg. cal.	Boiling-temp. °C.
100	100	46·85		77·75	100	59·29		61·52
90	67·8	61·60	59·60	64·65	96·1	61·83	60·59	64·30
80	47·2	68·47	65·64	55·77	90	64·50	62·79	67·00
70	34·6	73·00	72·75	50·80	83·0	67·15	64·26	69·50
60	25·4	76·75	76·39	47·25	75·0	70·13	68·04	71·75
50	18·5	79·85	79·09	44·25	65·0	73·40	71·55	73·80
40	12·7	82·15	81·41	41·65	53·0	77·15	75·76	75·58
30	8·0	84·05	83·25	39·40	40·6	81·25	80·10	77·12
20	4·28	85·50	84·70	37·60	27·2	85·55	84·82	78·40
10	1·72	86·30	85·74	36·15	13·6	90·00	89·55	79·58
0	0	86·44 [1]		34·75	0	94·35		80·65

Carbon Tetrachloride and Ethyl Acetate.					Ethyl Bromide and Benzene.			
CCl_4 in liquid wt. %	CCl_4 in vapour wt. %	Latent heat T kg. cal.	Latent heat H kg. cal.	Boiling-temp. °C.	C_2H_5Br in vapour wt. %	Latent heat T kg. cal.	Latent heat H kg. cal.	Boiling-temp. °C.
100	100	47·29		75·92	100	59·85		38·38
90	90·2	51·20	50·97	74·83	97·6	60·85	60·70	49·90
80	80·4	55·22	54·72	74·29	94·6	61·85	61·74	56·72
70	70·4	59·20	59·00	74·10	91·0	63·0	62·98	61·76
60	60·4	63·25	63·14	74·10	86·4	64·6	64·34	65·86
50	51·1	67·35	66·86	74·35	80·4	66·7	66·63	69·10
40	41·2	71·35	71·02	74·72	72·0	69·9	69·52	71·75
30	31·2	75·45	75·08	75·12	61·4	74·1	73·18	74·13
20	21·1	79·60	79·28	75·58	46·8	79·80	78·21	76·30
10	10·7	83·70	83·56	76·05	26·6	86·60	85·17	78·33
0	0	87·97		76·50	0	94·35		80·25

[1] Other observers have found values between 84·5 and 91·11.

Specific heat at 20° C.

Carbon tetrachloride .	0·62724	Chloroform . .	0·67219
Ether	1·4015	Benzene . .	1·13815

(CHART I)

heat of vaporisation of mixtures of non-reacting vapours with the equation : $C = a\alpha + w\beta$.

Benzene and Ethyl Alcohol.					Chloroform and Methyl Alcohol.			
C_6H_6 in liquid wt. %	C_6H_6 in vapour wt. %	Latent heat T kg. cal.	Latent heat H kg. cal.	Boiling-temp. °C.	$CHCl_3$ in vapour wt. %	Latent heat T kg. cal.	Latent heat H kg. cal.	Boiling-temp. °C.
100	100	94·45	94·43	79·75	100	59·32	59·32	61·37
90	76·4	101·0	105·05	69·54	88·7	80·0	79·72	53·65
80	71·4	111·6	115·56	68·20	84·2	104·0	100·1	53·66
70	68·7	124·5	126·11	67·76	81·5	125·2	120·54	54·52
60	66·0	137·4	136·67	67·97	78·0	143·4	140·95	55·94
50	62·4	150·6	147·22	68·41	72·3	161·6	161·36	57·52
40	58·2	163·9	157·78	69·00	64·0	180·2	181·76	59·07
30	52·4	176·7	168·33	70·26	54·1	200·6	201·1	60·68
20	44·0	188·3	178·60	71·86	41·7	221·0	222·5	62·38
10	31·4	195·8	189·44	74·40	25·2	242·3	242·99	64·05
0	0	200·3	200·3 [1]	78·12	0	263·4 [2]	263·4	64·86

Chloroform and Acetone.					Carbon Tetrachloride & Ethyl Alcohol.			
$CHCl_3$ in liquid wt. %	$CHCl_3$ in vapour wt. %	Latent heat T kg. cal.	Latent heat H kg. cal.	Boiling-temp. °C.	CCl_4 in vapour wt. %	Latent heat T kg. cal.	Latent heat H kg. cal.	Boiling-temp. °C.
100	100	59·34	59·32	61·25	100	46·85	46·85	75·92
90	94·7	72·3	65·77	63·02	87·1	67·1	60·17	64·30
80	81·5	78·1	72·23	63·84	83·2	82·5	77·48	63·88
70	65·9	83·7	78·69	63·41	81·5	97·7	92·79	64·42
60	52·3	90·2	85·14	62·19	79·4	112·5	108·11	65·32
50	39·8	96·8	91·60	61·03	76·8	127·2	123·42	66·64
40	29·4	103·1	98·06	59·91	72·0	141·7	138·74	68·35
30	20·3	108·9	104·57	58·83	64·7	157·0	154·05	70·25
20	12·35	114·1	110·97	57·79	54·6	171·5	169·37	72·44
10	5·30	119·1	117·43	57·00	40·0	186·0	184·68	74·82
0	0	123·88	123·88	55·97	0	200·3	200·3	77·91

In the above table kg. cal. signifies kilogram calories per kilogram; the unit therefore the small calorie.

[1] Andrews 202·4; Wirtz 205·1; Brown 216·4.
[2] Andrews 263·7; Wirtz 267·5; Brown 262·2.

TABLE 2 (CHART III)

Alcohol-content of liquid mixtures of alcohol and water, and of the vapours therefrom. Ratios of the liquids $\frac{w}{a} = f$ and of the vapours $\frac{w_d}{a_d} = f_d$; values of $\frac{\alpha + f\beta}{f - f_d}$ and $\frac{a + f_d\beta}{f - f_d}$. $\alpha = 205$. $\beta = 544$. Percentage figures from H. Bergström, amplified by the author.

Boil.-temp. °C.	Alcohol in liquid wt. %	$\frac{w}{a} = f$	Alcohol in vapour wt. %	$\frac{w_d}{a_d} = f_d$	$\frac{205 + f\,544}{f - f_d}$	$\frac{205 + f_d\,544}{f - f_d}$
	95	0·0526	95	0·0526	—	—
	94·5	0·0582	94·6	0·0571	215,300	214,526
	94·4	0·0593	94·5	0·0582	215,433	214,530
	94	0·0638	94·2	0·0616	108,935	108,346
	93·8	0·0661	94	0·0638	104,718	104,115
	93·5	0·0695	93·8	0·0661	71,418	70,850
	93·1	0·0741	93·5	0·0695	63,278	62,756
	93	0·0753	93·4	0·0707	53,456	52,914
	92·5	0·0811	93	0·0753	42,945	42,395
	92	0·0870	92·6	0·0799	35,482	34,988
	91·85	0·0887	92·5	0·0811	33,249	32,782
	91·5	0·0929	92·25	0·0840	28,695	28,150
	91·2	0·0965	92	0·0870	27,090	26,542
	91	0·0990	91·9	0·0881	23,905	23,364
	90·5	0·1050	91·5	0·0929	21,805	21,255
	90	0·1111	91·2	0·0965	18,200	17,756
	89·8	0·1136	91	0·0990	17,200	16,836
	89·5	0·1173	90·85	0·1007	16,234	15,678
	89·3	0·1198	90	0·1025	15,827	15,275
	89	0·1236	90·5	0·1050	14,810	14,236
	88·5	0·1299	90·15	0·1093	13,505	12,960
	88	0·1364	89·8	0·1138	12,398	11,840
	87·5	0·1429	89·5	0·1173	11,018	10,482
	87	0·1494	89·20	0·1211	10,189	9,568
	86·6	0·1521	89	0·1236	10,068	9,543
	86·5	0·1561	88·9	0·1249	9,289	8,741
	86	0·1628	88·6	0·1287	8,604	8,055
79·1	85·5	0·1696	88·3	0·1325	8,010	7,466
[78·4]	85	0·1765	88	0·1364	7,503	6,958
	84·5	0·1834	87·75	0·1396	6,959	6,410
	84	0·1905	87·5	0·1429	6,480	5,934
	83·5	0·1976	87·2	0·1468	6,146	5,603
	83·1	0·2034	87	0·1494	5,840	5,297
	83	0·2048	87·10	0·1494	5,705	5,155
79·2	82·5	0·2121	86·75	0·1527	5,386	4,840
79·3	82	0·2195	86·50	0·1561	5,116	4,549

Boil.-temp. °C.	Alcohol in liquid wt. %	$\frac{w}{a} = f$	Alcohol in vapour wt. %	$\frac{w_d}{a_d} = f_d$	$\frac{205 + f\,544}{f - f_d}$	$\frac{205 + f_d\,544}{f - f_d}$
	81·5	0·2270	86·2	0·1601	4906	4365
	81·1	0·2331	86	0·1628	4714	4186
79·4	81	0·2346	85·95	0·1634	4660	4131
	80·5	0·2422	85·7	0·1669	4468	3925
	80	0·2500	85·5	0·1696	4237	3686
	79·5	0·2579	85·25	0·1729	4056	3497
79·55	79	0·2658	85	0·1765	3955	3372
	78·5	0·2739	84·8	0·1793	3732	3177
	78	0·2821	84·6	0·1820	3585	3040
	77·9	0·2837	84·5	0·1834	3579	3033
	77·5	0·2903	84·35	0·1854	3471	2921
79·7	77	0·2987	84·2	0·1877	3310	2765
	76·5	0·3072	84	0·1905	3170	2629
	76	0·3158	83·8	0·1933	3074	2529
	75·5	0·3245	83·6	0·1962	2970	2427
	75·3	0·3280	83·55	0·1968	2920	2377
79·75	75	0·3333	83·5	0·1976	2846	2303
[79·2]	74·5	0·3423	83·3	0·2005	2727	2206
	74	0·3514	83·1	0·2034	2674	2130
	73·5	0·3605	82·9	0·2063	2602	2058
79·95	73	0·3699	82·7	0·2092	2537	1991
	72·5	0·3793	82·55	0·2115	2451	1907
	72	0·3889	82·4	0·2136	2377	1833
	71·5	0·3986	82·20	0·2166	2314	1771
80·1	71	0·4085	82	0·2195	2258	1716
	70·5	0·4184	81·85	0·2217	2200	1656
80·2	70	0·4286	81·7	0·2240	2141	1594
	69·5	0·4389	81·50	0·2270	2092	1550
80·3	69	0·4493	81·3	0·2300	2048	1504
	68·5	0·4599	81·10	0·2331	2006	1462
80·4	68	0·4706	80·9	0·2361	1963	1418
	67·5	0·4815	80·75	0·2382	1918	1375
	67	0·4925	80·6	0·2407	1876	1332
	66·5	0·5038	80·45	0·2430	1838	1294
80·5	66	0·5152	80·30	0·2453	1800	1254
	65·5	0·5267	80·2	0·2469	1759	1213
80·6	65	0·5385	80	0·2500	1720	1180
	64·5	0·5504	79·9	0·2516	1684	1140
80·65	64	0·5625	79·89	0·2531	1647	1103
	63·5	0·5748	79·70	0·2547	1614	1072
80·75	63	0·5873	79·6	0·2563	1583	1040
	62·5	0·6000	79·45	0·2586	1556	1011
[80·35]	62	0·6129	79·3	0·2610	1528	984
	61·5	0·6260	79·2	0·2626	1450	956
80·95	61	0·6393	79·1	0·2642	1477	930
81	60·5	0·6529	79	0·2658	1444	901

Boil.-temp. °C.	Alcohol in liquid wt. %	$\frac{w}{a} = f$	Alcohol in vapour wt. %	$\frac{w_d}{a_d} = f_d$	$\frac{205 + f\,544}{f - f_d}$	$\frac{205 + f_d\,544}{f - f_d}$
	60	0·6667	78·9	0·2674	1418	876
	59·5	0·6807	78·8	0·2690	1397	853
81·1	59	0·6949	78·7	0·2707	1370	828
	58·5	0·7094	78·55	0·2731	1351	810
81·2	58	0·7241	78·4	0·2755	1335	790
	57·5	0·7391	78·3	0·2771	1311	767
	57	0·7544	78·2	0·2787	1292	748
	56·5	0·7699	78·1	0·2804	1296	744
81·3	56	0·7857	78	0·2821	1254	709
	55·5	0·8018	77·9	0·2837	1237	693
81·4	55	0·8182	77·8	0·2854	1218	675
	54·5	0·8349	77·65	0·2878	1202	657
[80·9]	54	0·8519	77·5	0·2903	1189	645
81·55	53·5	0·8692	77·4	0·2920	1172	628
81·6	53	0·8868	77·3	0·2937	1154	612
	52·5	0·9048	77·2	0·2953	1143	599
81·7	52	0·9231	77·1	0·2970	1124	582
	51·5	0·9418	77	0·2987	1111	568
[81·5]	51	0·9608	76·90	0·3004	1098	555
81·8	50·5	0·9802	76·8	0·3021	1084	542
81·9	50	1·0000	76·7	0·3038	1075	530
	49·5	1·0202	76·55	0·3063	1062	519
82	49	1·0408	76·40	0·3089	1047	506
	48·5	1·0619	76·30	0·3106	1040	495
[81·8]	48	1·0833	76·2	0·3123	1028	483
	47·5	1·1008	76·05	0·3145	1022	477
82·28	47	1·1277	75·9	0·3175	1004	464
82·50	46·5	1·1505	75·75	0·3199	999	454
	46	1·1739	75·7	0·3210	983	444
	45·5	1·1978	75·5	0·3251	978	435
[82·1]	45	1·2222	75·4	0·3263	969	425
	44·5	1·2472	75·30	0·3280	960	412
82·6	44	1·2727	75·2	0·3298	950	407
	43·5	1·2989	75	0·3333	939	397
82·65	43	1·3256	74·9	0·3351	935	390
	42·5	1·3529	74·75	0·3375	928	383
[82·35]	42	1·3810	74·6	0·3405	918	375
	41·5	1·4096	74·5	0·3423	909	367
82·95	41	1·4390	74·3	0·3459	902	359
83	40·5	1·4691	74·15	0·3483	893	351
83·1	40	1·5000	74	0·3514	889	345
	39·5	1·5317	73·9	0·3532	876	337
83·3	39	1·5641	73·8	0·3550	869	330
	38·5	1·5974	73·7	0·3569	862	322
83·4	38	1·6316	73·6	0·3587	857	314
[83]	37·6	1·6596	73·55	0·3593	850	308

Boil.-temp. °C.	Alcohol in liquid wt. %	$\frac{w}{a} = f$	Alcohol in vapour wt. %	$\frac{w_d}{a_d} = f_d$	$\frac{205 + f\,544}{f - f_d}$	$\frac{205 + f_d\,544}{f - f_d}$
	37·5	1·6667	73·50	0·3605	849	307
83·5	37	1·7027	73·4	0·3624	840	300
	36·5	1·7397	73·25	0·3649	833	293
83·7	36	1·7778	73·1	0·3680	829	288
	35·5	1·8169	73	0·3699	823	281
	35	1·8571	72·8	0·3736	819	275
83·9	34·5	1·8986	72·65	0·3761	809	268
83·85	34	1·9412	72·5	0·3793	807	263
84·15	33·5	1·9851	72·35	0·3818	801	257
	33	2·0303	72·2	0·3850	794	252
	32·5	2·0769	72·05	0·3876	791	246
	32·3	2·0960	72	0·3889	786	243
84·3	32	2·1250	71·9	0·3908	784	241
	31·5	2·1746	71·75	0·3934	782	235
[83·9]	31	2·2258	71·60	0·3967	773	230
	30·8	2·2468	71·5	0·3986	771	228
	30·5	2·2787	71·4	0·4006	767	225
84·7	30	2·3333	71·2	0·4045	763	221
	29·5	2·3898	71	0·4085	758	216
84·8	29	2·4483	70·3	0·4129	750	210
	28·5	2·5088	70·6	0·4164	748	206
	28·3	2·5336	70·55	0·4174	745	204
85	28	2·5714	70·5	0·4184	743	201
	27·5	2·6364	70·25	0·4235	738	197
85·2	27	2·7037	70	0·4286	735	192
	26·5	2·7736	69·7	0·4347	732	189
85·4	26	2·8462	69·5	0·4389	729	185
	25·5	2·9063	69·3	0·4430	724	181
85·7	25	3·0000	69	0·4493	720	176
	24·5	3·0816	68·7	0·4556	716	172
	24·1	3·1494	68·5	0·4599	713	169
[85·4]	24	3·1667	68·4	0·4620	712	168
	23·5	3·2553	68·1	0·4681	709	165
	23·3	3·2919	68	0·4706	706	163
86·2	23	3·3478	67·7	0·4771	704	162
[85·9]	22·5	3·4444	67·5	0·4815	699	158
86·4	22	3·5455	67	0·4925	696	155
	21·5	3·6512	66·7	0·4993	693	155·7
86·7	21	3·7619	66·3	0·5083	690	148
	20·5	3·8781	65·9	0·5175	688	145
	20·1	3·9751	65·7	0·5221	683	141
87	20	4·0000	65·5	0·5267	683	141
87·05	19·5	4·1282	65	0·5383	681	138
87·4	19	4·2632	64·5	0·5504	680	136
	18·5	4·4054	64·1	0·5601	676	132
[87·3]	18·3	4·4645	63·9	0·5650	674	131

Boil.-temp. °C.	Alcohol in liquid wt. %	$\frac{w}{a} = f$	Alcohol in vapour wt. %	$\frac{w_a}{a_a} = f_a$	$\frac{205 + f\,544}{f - f_a}$	$\frac{205 + f_a\,544}{f - f_a}$
87·7	18	4·5556	63·5	0·5748	672	130
	17·5	4·7143	63	0·5873	670	127
	17·4	4·7471	62·8	0·5924	669	126
87·9	17	4·8824	62·4	0·6026	667	124
	16·6	5·0241	62	0·6129	664	122
	16·5	5·0606	61·9	0·6155	664	121
88·25	16	5·2500	61·2	0·6340	661	119
	15·5	5·4516	60·6	0·6502	659	116
88·55	15·4	5·4935	60·5	0·6529	659	115
	15	5·6667	60	0·6667	647	114
	14·5	5·8966	59·5	0·6807	651	111
	14·3	5·9930	59	0·6949	652	110
	14	6·1429	58·60	0·7065	650	109
89·4	13·8	6·2464	58	0·7241	650	108
	13·5	6·4074	57·8	0·7301	649	106
	13·3	6·5188	57·5	0·7391	648	105
89·7	13	6·6923	57	0·7544	646	104
	12·5	6·9365	56·3	0·7762	644	102
90·18	12·3	7·1301	56	0·7857	641	99
	12	7·3333	55·5	0·8018	641	98
	11·5	7·6957	54·5	0·8349	637	96
90·6	11·2	7·9286	54	0·8519	636	94
	11	8·0909	53·6	0·8657	636	93
91·05	10·7	8·3458	53	0·8868	635	92
	10·5	8·5238	52·6	0·9011	634	91
	10·47	8·5600	52·5	0·9048	633	90·6
	10·2	8·8039	52	0·9231	633	90
	10	9·0000	51·6	0·9380	632	89
	9·8	9·2040	51	0·9608	631	88
91·5	9·55	9·471	50·5	0·9802	631	87
	9·5	9·526	50·4	0·9841	629	86·5
	9·35	9·700	50	1·0000	626	87·8
	9·2	9·897	49·5	1·0202	626	85
	9	10·111	49·2	1·0325	626	84·4
92·1	8·75	10·430	48·5	1·0619	626	83·5
	8·55	10·695	48	1·0833	624	82·3
	8·5	10·765	47·8	1·0921	624	82
	8·4	10·905	47·5	1·1053	618	81·3
	8·2	11·195	47	1·1277	628	81·7
92·6	8	11·500	46·3	1·1598	627	80·7
	7·9	11·658	46	1·1739	626	80·5
	7·7	11·987	45·5	1·1978	624	79·5
	7·5	12·333	45	1·2222	622	78·1
	7·35	12·605	44·5	1·2472	621	78·2
	7·2	12·889	44	1·2727	621	77·2
	7·05	13·185	43·5	1·2989	621	76·6

Boil.-temp. °C.	Alcohol in liquid wt. %	$\frac{w}{a} = f$	Alcohol in vapour wt. %	$\frac{w_d}{a_d} = f_d$	$\frac{205 + f\,544}{f - f_d}$	$\frac{205 + f_d\,544}{f - f_d}$
	7	13·286	43·3	1·3095	619	76·6
	6·9	13·493	43	1·3256	619	75·8
	6·75	13·811	42·5	1·3529	618	75·5
	6·6	14·152	42	1·3810	618	74·8
	6·5	14·385	41·5	1·4096	618·2	75·2
93·8	6·3	14·873	41	1·4390	617·2	73·55
	6·2	15·129	40·5	1·4691	616·8	73·3
	6	15·667	39·8	1·5126	616	72·5
	5·9	15·949	39·5	1·5317	615·8	71·9
94·4	5·8	16·241	39	1·5641	615·4	72
	5·6	16·857	38·5	1·5974	613·3	70·2
	5·5	17·182	38	1·6316	613·7	70·1
	5·4	17·519	37·5	1·6667	613·2	70
	5·25	18·050	37	1·7027	613	69
	5·15	18·410	36·5	1·7397	613	69
	5	19·000	36	1·7778	612	68·1
	4·9	19·408	35·5	1·8169	612	67·8
95·15	4·8	19·833	35	1·8571	612	67·5
	4·7	20·277	34·5	1·8986	612	67·5
	4·6	20·739	34	1·9412	612	67
	4·5	21·222	33·5	1·9851	610	67·1
	4·4	21·727	33	2·0303	610	66·4
	4·22	22·697	32·5	2·0769	611	66·7
	4·2	22·810	32	2·1250	610	67·5
	4·1	23·390	31·5	2·1746	608	65·7
95·8	4	24·000	31·2	2·2051	608	64·2
	3·9	24·641	30·5	2·2787	607	62·5
	3·8	25·316	30	2·3333	607	64
	3·7	26·027	29·5	2·3898	606	63·6
	3·6	26·778	29	2·4483	606	63
	3·5	27·571	28·5	2·5088	606	62·5
	3·4	28·412	28	2·5714	605	61·7
96·6	3·3	29·303	27·5	2·6364	604	61·3
	3·2	30·250	27	2·7037	604	60·8
	3·1	31·258	26·5	2·7736	603	60·1
	3	32·333	26·3	2·8023	603	58·6
	2·95	32·898	25·5	2·9216	603	59·7
	2·98	33·722	25	3·0000	602	59·6
	2·81	34·587	24·5	3·0816	602	59·5
	2·73	35·630	24	3·1667	602	59
	2·66	36·594	23·5	3·2553	602	59·5
	2·6	37·462	23	3·3478	602	59·2
	2·5	39·000	22·5	3·444	602	58·3
	2·45	39·816	22	3·545	602	58·7
97·44	2·4	40·667	21·5	3·651	602	59·1
	2·2	42·478	20	4·000	601	61·7

Boil.-temp. °C.	Alcohol in liquid wt. %	$\frac{w}{a} = f$	Alcohol in vapour wt. %	$\frac{w_d}{a_d} = f_d$	$\frac{205 + f\,544}{f - f_d}$	$\frac{205 + f_d\,544}{f - f_d}$
	2·2	44·455	19·5	4·128	602	60·7
	2·10	46·619	19	4·263	600	59·5
	2	49·000	18·5	4·405	600	57
	1·9	51·632	18	4·555	600	56·9
	1·8	54·556	17·5	4·714	600	55·3
	1·75	56·143	16·5	4·060	600	57·6
	1·64	59·976	16	5·250	600	55·7
	1·6	61·500	15·5	5·451	600	56·3
	1·55	63·516	15	5·666	600	56·8
98·2	1·5	65·667	14·75	5·788	600	56
	1·47	67·027	14·5	5·896	600	55·6
	1·4	70·429	14	6·142	598	55
	1·3	76·923	13	6·692	597	54·6
	1·2	82·333	12·5	7·000	595	53
	1·05	94·238	11	8·090	597	53·1
	1	99·000	10·5	8·523	597	52·9
	0·9	110·11	9·6	9·417	594	52·7
99	0·8	124·06	8·72	10·46	595	51·9
	0·7	141·86	7·77	11·870	593	52·6
	0·6	165·67	6·78	13·749	594	50·6
	0·5	199·00	5·7	16·544	598	50·9
	0·4	249·00	4·52	21·124	596	50·7
	0·3	332·33	3·36	28·762	595	51·9
	0·2	499·00	2·22	44·045	594	52·7
	0·1	999·0	1·1	89·909	597	54
	0·09	1111	0·99	100·1	598	54·1
	0·08	1250	0·88	112·64	598	54·1
	0·07	1428	0·77	128·87	596	53·9
	0·06	1667	0·66	150·52	596	53·9
	0·05	2000	0·55	180·82	599	52·1
	0·04	2500	0·44	226·27	599	54·2
	0 03	3333	0·33	302·03	596	53·9
	0·02	5000	0·22	453·55	595	53·9
	0·01	10000	0·11	908·09	598	54·3

TABLE 3

Latent heat of vaporisation, heat expended on raising liquid to boiling-point, and total heat of vaporisation of mixtures of ethyl alcohol and water.

Mixture contains:		Boiling-temperature.	Latent heat.			Heat required to raise liquid to boiling-point				Total heat of mixture from 12° C.
						From 0° C.			From 12° C.	
Alcohol.	Water.		Alcohol.	Water.	Mixture.	Alcohol.	Water.	Mixture.	Alcohol.	
wt. %	wt. %	°C.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.
100	0	78	214·5	—	—	50·32	—	—	44·73	259·2
95	5	78·33	214·3	551·6	231·1	50·6	78·33	51·98	45·02	276·1
90	10	78·66	214	551·3	247·7	50·88	78·66	53·65	46·42	294·1
85	15	79	213·8	551	264·4	51·36	79	55·55	48·06	312·4
80	20	79·5	213·4	550·9	280·7	51·73	79·5	57·28	49·52	330·2
75	25	79·8	213·1	550·7	297·5	51·96	79·8	58·91	50·59	348·10
70	30	80·1	213	550·6	314·3	52	80·1	59·43	51·14	365·4
65	35	80·6	212·6	550·3	330·8	52·51	80·6	62·04	53·49	384·3
60	40	81	212·3	550	347·4	52·89	81	64·12	58·30	402·7
55	45	81·4	212	549·5	363·8	53·19	81·4	65·78	56·70	420·5
50	50	81·9	211·6	549·1	380·3	53·59	81·9	67·49	53·14	438·4
45	55	82·5	211·3	548·9	396·9	54·91	82·5	69·65	60·03	456·9
40	60	83	210·9	548·5	413·5	54·37	83	71·54	61·96	475·4
35	65	83·8	210·3	547·8	429·6	55·06	83·8	73·74	63·60	493·2
30	70	84·7	209·7	547·5	446·1	55·58	84·7	75·96	65·55	511·6
25	75	85·6	209·1	546·6	462·2	56·20	85·6	78·25	67·58	529·8
20	80	87	208·1	545·7	478·1	57·83	87	81·16	70·22	548·3
15	85	88·5	207·1	544·9	494·1	59·00	88·5	84·07	72·87	566·9
10	90	91·3	205·1	542·6	508·8	60·90	91·3	88·26	76·83	585·6
5	95	95·1	201·1	540	523·1	63·90	95·1	93·53	81·81	604·9
0	100	100	—	537	—	—	100	—	—	625·0

Specific heat of wash containing 3% dry matter:

Alcohol-content	4	5	6	7	8	9	10	11	12%
Specific heat	0·967	0·964	0·960	0·957	0·954	0·951	0·948	0·945	0·941

Excluding dry matter

Alcohol-content	1·5	3
Specific heat	1·00	0·99

Specific heat of water . . . = 1
,, ,, ,, alcohol . . . = 0·68
,, ,, ,, dry matter . . = 0·333

TABLE 4 (FIG. 9)

Percentage weight of low-boiling component (p_J) left in the residue ($a_J + w_J$) in the boiling-vessel after 5–99% of this component has been distilled off from the original charge and recovered as 95% distillate.

a_J represents the weight in kg. of low-boiling component left in residue when 100 kg. of the original charge contained 70–10 kg. of a.

Wt. % of a removed by distillation.	$a =$	70	60	50	40	30	20	10
0	p_J%	70	60	50	40	30	20	10
	a_J	70	60	50	40	30	20	10
5	p_J%	68·7	58·7	48·8	38·7	28·97	19·19	9·5
	a_J	66·5	57	47·5	38	28·5	19	9·5
10	p_J%	68	57·5	47·5	37·5	27·81	18·36	9·09
	a_J	63	54	45	36	27	18	9
15	p_J%	66·9	56·4	46	36·2	26·77	17·58	8·62
	a_J	59·5	51	42·5	34	25·5	17	8·5
20	p_J%	65·5	55	44·7	34·8	25·60	16·70	8·16
	a_J	56	48	40	32	24	16	8
25	p_J%	64·2	53·4	43·1	33·6	24·45	15·82	7·68
	a_J	52·5	45	37·5	30	22·5	15	7·5
30	p_J%	63	51·8	41·5	32	23·24	14·93	7·22
	a_J	49	52	35	28	21	14	7
35	p_J%	61·3	50·1	39·8	30·4	21·90	14	6·73
	a_J	45·5	39	32·5	26	19·5	13	6·5
40	p_J%	59·6	48·5	38	28·8	20·60	13·08	6·24
	a_J	42	36	30	24	18	12	6
45	p_J%	57·5	46·2	36	27·1	19·22	12·15	5·77
	a_J	38·5	33	27·5	22	16·5	11	5·5
50	p_J%	55·4	44	34	25·4	17·99	11·26	5·37
	a_J	35	30	25	20	15	10	5
55	p_J%	53	41·4	31·7	23·4	16·33	10·17	4·77
	a_J	31·5	27	22·5	18	13·5	9	4·5

Wt. % of a removed by distillation.	$a =$	70	60	50	40	30	20	10
60	p_J%	50·4	38·7	29·3	21·4	14·94	9·24	4·30
	a_J	28	24	20	16	12	8	4
65	p_J%	35·7	35·7	26·6	19·2	13·19	8·09	3·74
	a_J	24·5	21	17·5	14	10·5	7	3·5
70	p_J%	43·4	22·3	23·8	17	11·52	7·02	3·24
	a_J	21	18	15	12	9	6	3
75	p_J%	39·3	28·6	21·1	14·7	9·92	5·92	2·71
	a_J	17·5	15	12·5	10	7·5	5	2·5
80	p_J%	34·3	24·3	17·3	12	8·04	4·82	2·18
	a_J	14	12	10	8	6	4	2
85	p_J%	28·2	19·5	13·6	9·4	6·13	3·64	1·65
	a_J	10·5	9	7·5	6	4·5	3	1·5
90	p_J%	21	13·9	9·54	6·5	4·19	2·47	1·11
	a_J	7	6	5	4	3	2	1
95	p_J%	11·7	7·58	4·99	3·3	2·11	1·25	0·555
	a_J	3·5	3	2·5	2	1·5	1	0·5
96	p_J%	9·67	6·12	4·06	2·68	1·72	0·902	0·444
	a_J	2·8	2·4	2	1·6	1·2	0·8	0·4
97	p_J%	7·44	4·68	3	2·03	1·996	0·753	0·333
	a_J	2·1	1·8	1·5	1·2	0·9	0·6	0·3
98	p_J%	5·11	3·16	2·07	1·366	0·869	0·503	0·222
	a_J	1·4	1·2	1	0·8	0·6	0·4	0·2
99	p_J%	2·62	1·39	1·05	0·689	0·437	0·253	0·112
	a_J	0·7	0·6	0·5	0·4	0·3	0·2	0·1

TABLE 5 (FIG. 10)

If the original charge contains 70–10% of low-boiling component (a), and so much of the latter is removed as 95% wt. distillate that the residue contains only 10–0·01 kg. per 100 kg. of charge, this residue will contain p_J% of a. For an alcohol-water mixture, the reflux-heat required to reduce the percentage of a in the residue (p_J) down to 13–12 is 1200 kg. cal., and more to reduce it further; to reduce it down to 0·01% requires C_a kg. cal.

Low-boil. comp. in residue for 100 kg. initial charge kg.	$a =$	70	60	50	40	30	20	10
10	p_J%	27·14	21·09	16·50	14·18	12·44	11·05	10·0
	C_B	1,200	1,200	1,200	1,200	1,200	1,300	1,300
	C_a	19,340	22,300	25,575	29,065	32,225	35,355	38,415
9	p_J%	25·15	19·76	15·12	12·96	11·34	10·06	9·05
	C_B	1,200	1,200	1,200	1,200	1,300	1,300	1,350
	C_a	18,140	21,100	24,375	27,965	31,025	34,055	37,115
8	p_J%	23·14	17·66	13·70	11·69	10·22	9·05	8·13
	C_B	1,200	1,200	1,200	1,300	1,300	1,350	1,350
	C_a	16,940	19,900	23,175	26,765	29,725	32,705	35,765
7	p_J%	20·96	15·82	12·17	10·39	9·09	8·07	7·19
	C_B	1,200	1,200	1,250	1,300	1,350	1,400	1,400
	C_a	15,740	18,700	21,975	25,465	28,425	31,355	34,415
6	p_J%	18·46	13·89	10·66	9·01	7·87	6·95	6·23
	C_B	1,200	1,200	1,300	1,350	1,400	1,400	1,400
	C_a	14,540	17,500	20,675	24,165	27,075	29,955	33,015
5	p_J%	15·84	11·86	9·05	7·65	6·67	5·85	5·25
	C_B	1,200	1,300	1,350	1,400	1,400	1,450	1,450
	C_a	13,339	16,300	19,375	22,815	25,675	28,555	31,615
4	p_J%	13·10	9·73	7·37	6·23	5·41	4·74	4·26
	C_B	1,200	1,300	1,400	1,400	1,500	1,500	1,500
	C_a	12,139	15,000	17,925	21,415	24,275	27,105	30,165
3	p_J%	10·18	7·50	5·65	4·75	4·12	3·75	3·22
	C_B	1,400	1,500	1,600	1,600	1,700	1,750	2,000
	C_a	10,939	13,700	16,525	20,015	22,775	25,605	28,665
2	p_J%	7·09	5·13	3·84	3·22	2·78	2·44	2·07
	C_B	1,400	1,700	2,000	2,700	3,450	3,500	3,700
	C_a	9,539	12,200	15,025	18,415	21,075	23,855	26,665
1	p_J%	3·66	2·64	1·96	1·64	1·41	1·23	1·10
	C_B	314	439	577	776	853	975	1,095
	C_a	8,139	10,499	12,725	15,716	18,626	20,757	22,966

TABLE 6

Mean ratios of liquid in, and vapour from, the boiling-vessel.

Alcohol-content at start and at end of distillation wt. %	Ratio of liquid mixture at start f_O	Mean Ratio of liquid in boiling-vessel $f_{U\,\text{mean}}$	Mean Ratio of vapour in boiling-vessel $f_{u\,\text{mean}}$	Diff. between f_O and $f_{u\,\text{mean}}$ $f_O - f_{u\,\text{mean}}$	Value of fraction $\frac{a - f_{u\,\text{mean}}\beta}{f_O - f_{u\,\text{mean}}}$
1—0·059	99	435	36·30	62·7	206
1·62—0·059	61	247	21	40	288
2·42—0·059	40	197	16	24	371
4·24—0·059	22·69	126·9	10·257	12·433	461
5·25—0·059	18	97	8·3	9·7	483
6·10—0·059	15	82·33	7	8	500
7·24—0·059	12·87	71·88	5·987	6·883	520
10—0·059	9	55·31	4·85	4·15	630
15—0·059	5·667	33·67	2·919	2·748	645
20—0·059	4	23·34	2·094	1·906	706
25—0·059	3	17·502	1·618	1·382	785
30—0·059	2·333	12·86	1·245	1·088	819
35—0·059	1·857	10·291	1·041	0·816	944
40—0·059	1·5	8·39	0·890	0·610	1130
45—0·059	1·222	6·618	0·752	0·470	1308
50—0·059	1	5·073	0·6295	0·3705	1479

TABLE 7

Column 1 gives the weight of alcohol in the residue when a 50 : 50 mixture is so vaporised that the vapour at once leaves the residue, and 1 kg. alcohol is distilled off at a time (for a mixture containing 15% or less, portions of 0·5, 0·25, 0·2, 0·01 kg. of alcohol). Column 2 gives the ratio of the residue; column 3 the ratio of the vapour; column 4 the alcohol-content of the residue; and column 5 the mean ratio of the residue between two alcohol-contents lying fairly wide apart (indicated by ††).

a and a_R kg.	f_R	f_d	Wt. %	f_{Rm}	a and a_R kg.	f_R	f_d	Wt. %	f_{Rm}
50	1·000	0·3038	50		17	2·125	0·391	32	
49	1·0143	0·3050	49·65		16	2·231	0·397	31	
48	1·0280	0·3073	49·3						†
47	1·0430	0·3088	48·9		15	2·350	0·402	29·8	
46	1·0550	0·3095	48·67		14·5	2·415	0·410	29·3	
45	1·0698	0·3112	43·3		14	2·484	0·412	28·7	
44	1·0820	0·3120	48		13·5	2·553	0·418	28·1	
43	1·0970	0·3135	47·7		13	2·629	0·423	27·6	30—23·5%
42	1·1100	0·3158	47·32		12·5	2·712	0·429	26·9	$f_{Rm}=2·749$
41	1·1290	0·3180	46·97		12	2·806	0·436	26·3	$f_{dm}=0·4248$
40	1·1410	0·3188	46·70	50—40%	11·5	2·906	0·443	25·6	
39	1·1570	0·3200	46·4	$f_{Rm}=1·1882$	11	3·008	0·450	25	
38	1·1740	0·3210	46·2	$f_{dm}=0·3231$	10·5	3·120	0·459	24·25	
37	1·1990	0·3250	45·49		10	3·253	0·468	23·5	
36	1·2180	0·3252	45·1						†
35	1·2400	0·3266	44·65		9·75	3·310	0·474	23·29	
34	1·2660	0·3294	44·22		9·5	3·370	0·478	22·88	
33	1·2980	0·3333	43·63		9·25	3·445	0·4815	22·5	
32	1·3250	0·3350	43		9	3·530	0·4885	22·05	23·5—20%
31	1·3480	0·3360	42·6		8·75	3·664	0·4967	21·5	$f_{Rm}=3·636$
30	1·3790	0·3400	42·1		8·5	3·710	0·5040	21·2	$f_{dm}=0·4837$
29	1·4110	0·3425	41·4		8·25	3·799	0·510	20·8	
28	1·4470	0·3470	40·92		8	3·900	0·519	20·4	
27	1·4870	0·3498	40·20		7·75	3·999	0·522	20	
				†					†
26	1·532	0·3530	39·4		7·5	4·096	0·535	19·63	
25	1·576	0·3558	38·9		7·25	4·220	0·543	19·63	
24	1·625	0·3570	38·1		7	4·335	0·555	18·75	
23	1·979	0·3610	37·4	40—30%	6·75	4·500	0·570	18·21	20—10%
22	1·738	0·3650	36·6	$f_{Rm}=1·831$	6·5	4·650	0·581	17·70	$f_{Rm}=6·1207$
21	1·800	0·3690	35·6	$f_{dm}=0·3621$	6·25	4·800	0·597	17·25	$f_{dm}=0·794$
20	1·865	0·3740	35		6	4·977	0·608	16·75	
19	1·940	0·379	34		5·75	5·167	0·625	16·24	
18	2·029	0·385	33		5·5	5·369	0·642	15·7	

a and a_R kg.	f_R	f_d	Wt. %	f_{Rm}	a and a_R kg.	f_R	f_d	Wt. %	f_{Rm}
5·25	5·586	0·660	15·2		1·2	20·15	1·887	4·74	
5	5·832	0·667	14·62		1	23·77	2·189	4·22	
4·75	6·095	0·702	14·10						†
4·50	6·398	0·729	13·5	20—10%	0·9	26·10	2·397	3·71	
4·25	6·721	0·757	12·95	$f_{Rm}=6·1207$	0·8	29·06	2·624	3·32	
4	7·195	0·785	12·3	$f_{dm}=0·794$	0·7	32·77	2·797	2·80	
3·75	7·530	0·817	11·72		0·6	37·65	3·348	2·60	4·25—1%
3·5	7·990	0·858	11·11		0·5	44·46	4·128	2·20	$f_{Rm}=49·87$
3·25	8·531	0·902	10·52		0·4	54·50	4·714	1·80	$f_{dm}=3·747$
3	8·891	0·930	10·15		0·3	71·03	6·223	1·40	
				†	0·2	102·4	8·54	1	
2·75	9·600	0·992	9·43						†
2·5	10·500	1·067	8·71	10—7·25%	0·1	196	16·54	0·50	
2·25	11·54	1·1628	8·04	$f_{Rm}=11·11$	0·08	241	21·12	0·40	
2	12·80	1·268	7·24	$f_{dm}=1·1224$	0·06	314	28·56	0·3	1·4—0·5%
				†	0·04	453	39	0·29	$f_{Rm}=36·30$
1·8	14·05	1·366	6·68	7·25—4·25	0·02	870	86	0·16	$f_{dm}=720$
1·6	15·62	1·472	6·03	$f_{Rm}=16·848$	0·01	1720	158	0·059	
1·4	17·56	1·667	5·42	$f_{dm}=1·716$					

Mean Ratio of the Residue

Between	f_{Rm}	%	Between	f_{Rm}	%	Between	f_{Rm}	%
50—45	1·1011	47·6	35—20	2·634	27·5	50—7·24	2·309	30·3
50—40	1·191	45·6	30—20	2·965	25·7	45—7·24	2·816	26·2
45—40	1·333	42·85	25—20	3·497	22·2	40—7·24	3·350	23
50—35	1·333	42·85	50—15	1·92	34·2	35—7·24	3·824	20·7
45—35	1·551	39·1	45—15	2·206	31·3	30—7·24	4·426	18·45
40—35	1·688	37·2	40—15	2·687	27·15	25—7·24	5·420	15·55
50—30	1·444	40·9	35—15	2·987	25·1	20—7·24	6·525	13·30
45—30	1·686	37·2	30—15	3·399	22·3	15—7·24	8·204	10·80
40—30	1·974	33·6	25—15	4·041	20	10—7·24	11·110	8·25
35—30	2·081	32·4	20—15	4·700	17·5	50—4·25	2·615	27·65
50—25	1·597	38·5	50—10	2·165	31·6	45—4·25	3·203	23·8
45—25	1·878	34·7	45—10	2·624	27·6	40—4·25	3·846	20·65
40—25	2·185	31·4	40—10	3·110	24·3	35—4·25	4·475	18·25
35—25	2·361	30·6	35—10	3·512	22·2	30—4·25	5·262	15·95
30—25	2·642	27·5	30—10	4·054	20	25—4·25	6·569	13·2
50—20	1·739	—	25—10	4·900	16·95	20—4·25	8·051	11
45—20	2·066	32·70	20—10	5·840	14·6	15—4·25	10·265	8·9
40—20	2·400	29·4	15—10	7·235	12·15	10—4·25	14·389	6·50

TABLE 8

Mean ratio and mean alcohol-content, f_{Bm} and p_B, of the residue when distilling mixtures (alcohol : water) of 50–10% strength; and the mean reflux-heat C_{Rm} when rectifying to 96% volume.

Final alcohol-content wt. %		Alcohol-content of mixture at start.									
		10	15	20	25	30	35	40	45	50% wt.	
0·059	p_B	1·73	2·898	4·1	5·4	7·2	8·85	10·65	13·15	16·45	%
	f_{Bm}	55·31	33·67	23·34	17·502	12·86	10·291	8·39	6·628	5·073	—
	C_{Rm}	2600	2000	1500	1100	1100	1100	1100	1100	1150	kg. cal.
1	p_B	3·799	5·59	7·4	9·3	11·7	13·85	16·25	19·2	23	%
	f_{Bm}	25·52	16·947	12·49	9·782	7·522	6·214	5·2	4·2	3·35	—
	C_{Rm}	1400	1100	1100	1100	1100	1100	1100	1100	1000	kg. cal.
2	p_B	5·25	7·15	9	11	13·25	15·75	18·8	21·25	26	%
	f_{Bm}	18·8	13	10·19	8	6·54	5·33	4·49	3·7	2·88	—
	C_{Rm}	1250	1100	1100	1100	1100	1100	1050	1050	1000	kg. cal.
4·25	p_B	6·5	8·9	11	13·2	15·97	18·3	20·65	23·8	27·65	%
	f_{Bm}	14·389	10·265	8·051	6·569	5·262	4·475	3·846	3·203	2·615	—
	C_{Rm}	1100	1100	1100	1100	1100	1100	1000	1000	1000	kg. cal.
7·24	p_B	8·25	11	13·25	15·58	18·45	20·75	23	26·2	30·25	%
	f_{Bm}	11·11	8·204	6·525	5·42	4·426	3·824	3·35	2·816	2·309	—
	C_{Rm}	1100	1100	1100	1100	1100	1100	1000	1000	1000	kg. cal.
10	p_R	—	12·15	14·6	16·9	19·8	22·2	24·3	27·6	31·6	%
	f_{Bm}	—	7·235	5·84	4·91	4·054	3·512	3·11	2·624	2·164	—
	C_{Rm}	—	1100	1100	1100	1100	1000	1000	1000	1000	kg. cal.
15	p_B	—	—	17·55	19·85	22·7	25·1	27·15	31·2	34·2	%
	f_{Bm}	—	—	4·7	4·041	3·399	2·987	2·687	2·206	1·924	—
	C_{Rm}	—	—	1100	1100	1000	1000	1000	1000	1000	kg. cal.
20	p_B	—	—	—	22·2	25·2	27·5	29·4	32·65	36·5	%
	f_{Bm}	—	—	—	3·497	2·965	2·634	2·4	2·062	1·739	—
	C_{Rm}	—	—	—	1000	1000	1000	1000	1000	1000	kg. cal.
25	p_B	—	—	—	—	27·4	29·7	31·4	34·8	38·5	%
	f_{Bm}	—	—	—	—	2·642	2·361	2·185	1·878	1·597	—
	C_{Rm}	—	—	—	—	1000	1000	1000	1000	1000	kg. cal.
30	p_B	—	—	—	—	—	32·45	33·6	37·25	40·9	%
	f_{Bm}	—	—	—	—	—	2·081	1·974	1·686	1·444	—
	C_{Rm}	—	—	—	—	—	1000	1000	1000	1000	kg. cal.
35	p_B	—	—	—	—	—	—	37·2	39·2	42·83	%
	f_{Bm}	—	—	—	—	—	—	1·688	1·551	1·333	—
	C_{Rm}	—	—	—	—	—	—	1000	1000	1000	kg. cal.
40	p_B	—	—	—	—	—	—	—	42·85	45·6	%
	f_{Bm}	—	—	—	—	—	—	—	1·333	1·191	—
	C_{Rm}	—	—	—	—	—	—	—	1000	1000	kg. cal.
45	p_B	—	—	—	—	—	—	—	—	47·6	%
	f_{Bm}	—	—	—	—	—	—	—	—	1·1011	—
	C_{Rm}	—	—	—	—	—	—	—	—	1000	kg. cal.

TABLE 9

Calculation of the alcohol-content of the mixture in the upper part of a two-compartment boiling-vessel at the moment when the liquid is run into the lower part.

1	2	3	4	5	6	7	8	9	10
Alcohol in mixture $a + w$ wt. %	Preheat. C_v kg. cal.	Heat of product. C_e kg. cal.	Mean ratio of upper liquid. f_{Rm}	Reflux heat. C_{Rm} kg. cal.	C_d = sum of cols. 2, 3, and 5. kg. cal.	$f - f_e$	$\frac{1}{f - f_e}$	Product of cols. 6 and 8.	Alcohol in mixture running into lower part $a_0 + w_0$ wt. %
For spirit of 85·7% wt. = 90% vol.									
50	144	298	1·74	165	607	0·831	1·200	720	21
45	162	,,	2·624	192	652	1·053	0·952	619	9·7
40	184	,,	3·35	220	702	1·331	0·752	528	7·3
35	212	,,	4·475	270	780	1·688	0·592	462	4·25
30	251	,,	6·00	350	899	2·164	0·463	416	3·25
25	304	,,	8·00	440	1042	2·831	0·353	367	2·42
20	384	,,	11·00	590	1272	3·831	0·261	331	2·00
15	562	,,	15·40	850	1710	5·498	0·182	318	1·80
10	784	,,	24·10	1200	2282	8·831	0·113	255	1·05
For spirit of 94·6% wt. = 96·5% vol.									
50	144	236	1·0	1000	1380	0·943	1·0605	1463	50·2
45	162	,,	1·222	1000	1398	1·165	0·862	1206	44·3
40	184	,,	1·65	1000	1420	1·443	0·694	985·5	36
35	212	,,	2·20	1000	1448	1·818	0·5524	800	27·5
30	251	,,	3·40	1000	1487	2·276	0·440	653	15·1
25	304	,,	5·30	1100	1640	2·943	0·340	557·6	7·95
20	384	,,	7·35	1300	1920	3·943	0·254	487	5·25
15	562	,,	10·26	2000	2798	5·610	0·178	450	4·20
10	784	,,	19·0	2700	3720	8·943	0·111	412	3·23

TABLE 10

Calculation of the alcohol-content of the mixture in the upper part of a two-compartment boiling-vessel as the mixture is discharged into the lower compartment. Test of the accuracy of Table 9. The alcohol-content is here calculated from the values of $f_{u\,\text{mean}}$, a_u, w_v and C_u given in Table 7.

$$a + \text{w} = 100 \text{ kg.}$$

1 Alcohol in original mixture $a + w_u$ wt. %	1 $w - w_e$ kg.	3 $f_{u\,\text{mean}}$	4 C_d kg. cal.	5 $205 + 544 f_u$ kg. cal.	6 $\frac{1}{205 + 544 f_u}$	7 a_u kg.	8 w_u kg.	9 $w - w_e + w_u + a_u$ kg.	10 $\frac{1}{w - w_e + w_u + a_u}$	11 Alcohol in run-off to lower compt. wt. %
For spirit of 85·7% wt. = 90% vol.										
50	41·65	2·0	30,350	1,292	0·000775	23·48	46·96	112·0	892	20·95
45	47·49	4·9	29,340	2,870	0·000348	10·19	49·8	108·5	920	9·38
40	53·32	5·9	28,080	3,414	0·000293	8·233	48·55	110	909	7·48
35	59·26	10·2	27,300	5,754	0·000174	4·78	48·60	112·5	892	4·25
30	64·29	13	26,970	7,277	0·0001373	3·69	47·90	116·5	860	3·17
25	70·83	16	26,100	8,909	0·0001122	2·92	46·75	120·5	830	2·42
20	76·64	18·5	25,400	10,269	0·0000971	2·466	45·57	131·0	763	1·883
15	82·50	19·8	25,650	10,976	0·0000909	2·327	46·11	131·9	763	1·80
10	88·33	30	22,820	17,070	0·0000587	1·336	42·0	131·6	763	1·02
For spirit of 94·6% wt. = 96·5% vol.										
50	47·15	0·625	69,000	540	0·001852	127·6	78·5	253	395	50·3
45	52·74	0·727	62,900	600	0·001667	105·0	75·3	233	429	45·4
40	57·72	1·000	56,800	749	0·001335	75·70	75·7	209	478	36·18
35	63·01	1·440	50,600	988	0·001012	51·16	73·6	187·8	535	27·3
30	68·29	3·000	44,610	1,837	0·000545	24·32	72·96	165·6	606	14·72
25	73·575	5·600	41,000	3,250	0·0003076	12·66	70·50	156·7	641	8·07
20	78·86	8·300	38,400	4,717	0·0002128	8·14	67·5	154·5	649	5·28
15	84·145	10·250	42,000	5,755	0·0001737	7·28	74·6	166·0	602	4·38
10	89·43	13·000	37,200	7,275	0·0001374	5·09	66·1	160·6	625	3·18

TABLE 11 (Chart V)

Ethyl Alcohol and Water (Bergström)

Amount of reflux heat C_R required in rectifying columns to produce 1 kg. of alcohol as spirit of 85·76, 92·37, 94·61% wt. (90, 95, 96·5% vol.) from aqueous mixtures containing from 93 to 0·5% of alcohol.

Initial alcohol-content		Heat needed to obtain 1 kg. alcohol as spirit of			Initial alcohol-content		Heat needed to obtain 1 kg. alcohol as spirit of		
of liquid.	of vapour.	85·76% (90) C_R 0·1662	92·37% (95) C_R 0·0825	94·61% (96·5) C_R 0·0571	of liquid.	of vapour.	85 76% (90) C_R 0·1662	92·37% (95) C_R 0·0825	94·61% (96·5) C_R 0·0571
wt. %	wt. %	kg. cal.	kg. cal.	kg. cal.	wt. %	wt. %	kg. cal.	kg. cal.	kg. cal.
93	93·4	—	—	726	32	71·9	176	241	262
92	92·6	—	—	807	30	71·2	182	246	265
90	91·2	—	254	717	28	70·5	187	250	268
88	89·8	—	388	660	26	69·5	199	260	273
86	88·6	—	399	619	24	68·4	211	270	288
84	87·5	—	391	558	22	67·0	227	285	303
82	86·5	—	377	507	20	65·5	247	303	321
80	85·5	14·8	365	475	18	63·5	275	331	348
78	84·6	56·5	356	447	16	61·2	309	365	381
76	83·8	83·1	340	417	14	58·6	351	406	422
74	83·1	99·3	323	390	12	55·5	408	461	478
72	82·4	112·3	311	373	10	51·6	488	540	557
70	81·7	123·6	303	357	9	49·2	542	595	610
68	80·9	135·0	298	350	8	46·3	620	667	687
66	80·3	142·3	291	338	7	43·3	705	760	773
64	79·8	143·5	282	323	6	39·8	831	880	898
62	79·3	145	273	312	5	36·0	985	1,040	1,055
60	78·9	145	262	298	4	31·1	1,240	1,288	1,307
58	78·4	145	258	290	3	26·3	1,591	1,640	1,658
56	78·0	146	248	281	2·5	22·5	1,928	2,005	2,023
54	77·5	147	244	277	2	18·5	2,533	2,587	2,605
52	77·1	148	240	268	1·5	14·75	3,360	3,408	3,426
50	76·7	149	238	266	1	10·5	4,990	5,038	5,050
48	76·2	150	236	262	0·5	5·7	9,751	9,790	9,850
46	75·7	151	234	261	0·4	—	—	—	12,510
44	75·2	156	235	260	0·3	—	—	—	17,136
42	74·6	160	237	260	0·2	—	—	—	26,036
40	74·0	164	239	260	0·1	—	—	—	53,670
38	73·6	165	236	259	0·08	—	—	—	66,976
36	73·1	167	237	258	0·06	—	—	—	90,000
34	72·5	172	239	260	0·04	—	—	—	135,148

TABLE 12 (CHART VI)

Ethyl Alcohol and Water

Rectifying Columns

Alcohol-content of the liquid and vapour on every plate of rectifying columns when a final vapour ranging from 50% to 90% wt. is produced with a reflux-heat expenditure ranging from 5000 to 300,000 kg. cal. per 10 kg. of alcohol.

No. of plate from top.	$C_R = 100{,}000$		$C_R = 150{,}000$		$C_R = 200{,}000$		$C_R = 250{,}000$		$C_R = 300{,}000$	
	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %
Rectification up to 50% wt. = 58% vol. per 10 kg. alcohol.										
	9·35	50	9·35	50	9·35	50	9·35	50	9·35	90
1	1·30	13·1	1·20	12	1·12	11·3	1·05	10·9	0·99	10·7
2	0·55	6	0·40	4·4	0·30	3·4	0·29	3·3	0·22	2·75
3	0·50	5·45	0·23	3·79	0·29	2·85	0·25	2·5	0·18	1·95
Rectification up to 75% wt. = 81% vol. per 10 kg. alcohol.										
	43·6	75	43·6	75	43·6	75	43·6	75	43·6	75
1	7·7	45·1	7·55	44·65	7·45	44·55	7·4	44·2	7·31	44·1
2	1·13	12·1	1	10·6	0·95	9·75	0·9	9·6	0·85	8·81
3	0·53	6·15	0·4	4·4	0·31	3·5	0·275	3·1	0·24	2·6
4	0·48	5·5	0·35	3·85	0·28	3·2	0·22	2·4	0·195	2

Rectification up to 85·76% wt. = 90% vol. per 10 kg. alcohol.

	$C_R = 5{,}000$		$C_R = 6{,}000$		$C_R = 7{,}000$		$C_R = 8{,}000$		$C_R = 9{,}000$	
	80·35	85·75	80·35	85·75	80·35	85·75	80·35	85·76	80·35	85·76
1	73·25	82·5	71·8	82·3	71·15	82·1	78·8	81·9	78·75	81·75
2	55·5	77·85	52·28	77·15	49·35	76·5	45·25	75·5	43·2	74·9
3	24·7	68·8	21	66·3	18·35	63·47	15·75	60	13·4	57·7
4	11·5	61·70	10	51·55	8·6	48·25	7·6	45	6·6	41·75
5	11·1	53·9	8·5	47·9	7·35	44·8	6·3	41·1	5·6	38·4
6	9·9	51·5	8·4	47·25	7·20	44	6·25	40·75	5·55	38·25
7	9·9	51·4	—	—	—	—	—	—	—	—

	$C_R = 10{,}000$		$C_R = 12{,}000$		$C_R = 15{,}000$		$C_R = 20{,}000$		$C_R = 25{,}000$	
	80·35	85·75	80·35	85·75	80·35	85·75	80·35	85·75	80·35	85·75
1	70	81·7	69·7	81·55	69·4	81·4	69	81·25	68·4	81·05
2	43·5	75	37·5	73·5	34·2	72·6	31	71·6	27·9	70·4
3	13	57·05	9·9	51·45	8·4	47·45	6·7	42·2	5·55	38·15
4	6·35	39·7	4·8	35	3·9	30·6	2·95	25·2	2·4	21·4
5	5·1	36·3	4·21	32·2	3·3	27·6	2·4	22·75	2·1	19·1

No. of plate from top.	$C_R = 30{,}000$		$C_R = 35{,}000$		$C_R = 60{,}000$		$C_R = 80{,}000$		$C_R = 100{,}000$	
	Liq. %.	Vap. %.	Liq. %.	Vap. %.	Liq. %.	Vap. %.	Liq. %.	Vap. %.	Liq. %.	Vap. %.
	Rectification up to 85·76% wt. = 90% vol.									
	80·38	85·75	80·38	85·75	80·38	85·75	80·38	85·75	80·38	85·75
1	72	82·3	71·5	82·2	66	80·45	65·9	80·3	65·7	80·6
2	39	73·8	36·6	73·3	22·5	67·5	22	67	21	66·3
3	7·9	45·75	6·8	42·9	3·36	27·7	3·05	26	2·81	24·3
4	2·3	21	2·05	18·7	1·2	12	0·89	8·72	0·7	7·7
5	1·75	17	1·55	14·8	0·9	0·96	0·7	7·2	0·5	5·7

Rectification up to 88·38% wt. = 92% vol.

	$C_R = 5{,}000$		$C_R = 6{,}000$		$C_R = 7{,}000$		$C_R = 8{,}000$		$C_R = 10{,}000$	
	85·5	88·38	85·5	88·38	85·5	88·38	85·5	88·38	85·5	88·38
1	82·2	86·55	82	86·5	81·9	86·4	81·7	86·3	81·1	86
2	77·9	84·5	76·9	84·15	76·1	83·85	75·3	83·6	73·4	83·25
3	71	82	68·25	81	65	79·95	62	79·3	52·5	77·2
4	57·75	78·35	46	75·35	36	73·1	28	70·5	17·5	63
5	30·3	71·25	18·4	63·9	13·15	57·2	10·05	51·8	6·8	42·5
6	14·4	59·2	10	51·5	8·1	46·7	6·8	42·8	5·3	37·15
7	11·1	53·65	8·2	47·15	7·35	44·45	6·42	41·4	5·1	36·3
8	10·5	52·6	8·15	47	7·3	44·4	6·3	40·9	5·1	36·2

Rectification up to 90% wt. = 93·25% vol. per 10 kg. alcohol.

	$C_R = 5{,}000$		$C_R = 6{,}000$		$C_R = 7{,}000$		$C_R = 8{,}000$		$C_R = 9{,}000$	
	88·2	90	88·2	90	88·2	90	88·2	90	88·2	90
1	86·5	88·9	86·3	88·8	86·2	88·75	86·1	88·7	86	88·6
2	84·25	87·7	84	87·5	83·7	87·3	83·45	87·2	83·1	87
3	86·4	82·5	81	85·95	80·3	85·6	79·8	85·05	78·7	84·9
4	80	85·5	76·8	84	74·75	83·4	71·75	82·4	70	81·7
5	76·7	84·1	68·4	81·2	63·1	79·65	54	77·5	47·8	76·3
6	70·5	81·5	49·5	76·70	33·5	72·3	20·5	65·9	15·5	60·9
7	58	78·4	21·1	66·4	12·5	56·3	8·55	48	7·1	43·7
8	32	71·9	10·8	55	8·3	47·25	6·75	42·5	5·95	39·6
9	15	60	9	49·2	7·5	45	6	41·6	5·85	39·25
10	11·33	54·25	—	—	—	—	—	—	—	—

TABLE 13 (CHART VI)

Ethyl Alcohol and Water

Rectifying Columns

Alcohol-content of liquid and vapour on every plate in a rectifying column when a final vapour of 92·46% wt. (95% vol.) is being produced with a heat-expenditure C_R ranging from 5,000 to 40,000 kg. cal. for every 10 kg. of alcohol recovered.

Rectification up to 92·46% wt. = 95% vol.

No. of plate from top.	$C_R = 5{,}000$		$C_R = 6{,}000$		$C_R = 7{,}000$		$C_R = 8{,}000$		$C_R = 9{,}000$	
	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %
	91·85	92·57	91·85	92·57	91·85	92·57	91·85	92·57	91·85	92·57
1	91·25	92·05	91·2	92	91·2	92	91·2	91·95	91·1	91·95
2	90·9	91·6	90·65	91·6	90·55	91·5	90·5	91·48	90·4	91·47
3	90·25	91·39	90	91·13	89·9	91·1	89·7	90·99	89·6	90·9
4	89·7	91	89·4	90·79	89·25	90·6	89	90·5	88·7	90·3
5	89·5	90·7	88·9	90·38	88·5	90·2	88·2	89·9	87·75	89·7
6	88·85	90·4	88·2	89·95	87·7	89·2	87·2	89·35	86·3	88·8
7	88·5	90·17	87·5	89·6	86·8	89	86	88·6	84·4	87·6
8	88·1	89·9	86·9	89·1	85·7	88·49	84·4	87·7	81·5	86·2
9	87·79	89·7	86·1	88·7	84·1	87·6	82·1	86·55	77	84·2
10	87·4	89·4	85·25	88·15	82·2	86·55	78·6	84·9	68	80·9
11	86·90	89·2	84	87·5	79·45	85·2	72	82·4	47·4	76
12	86·5	88·95	82·5	86·7	74·5	83·3	55·98	78	18·9	64·4
13	86	88·59	80·5	85·7	65·2	80·1	23·5	68·1	7·8	45·75
14	85·55	88·30	78·1	84·65	41	74·4	9·33	50	6·1	40·2
15	85	88	73·7	82·99	18·20	63·70	7	43·35	5·85	39·25
16	84·38	87·7	65·95	80·5	9·4	50·2	6·7	42·33	—	—
17	83·65	87·30	46	75·7	7·90	46	—	—	—	—
18	82·75	86·85	19·5	65·12	7·4	45·40	—	—	—	—
19	81·8	86·3	10·7	53·1	7·30	45·30				
20	80·5	85·7	9·25	50	—	—	—	—	—	—
21	78·85	84·9	9	49·25	—	—	—	—	—	—
22	76·5	84	—	—	—	—	—	—	—	—
23	73	82·6	—	—	—	—	—	—	—	—
24	67·6	80·6	—	—	—	—	—	—	—	—
25	43·8	75·1	—	—	—	—	—	—	—	—
26	20·8	66·2	—	—	—	—	—	—	—	—
27	13	57	—	—	—	—	—	—	—	—
28	11·35	54·3	—	—	—	—	—	—	—	—
29	11	53·65	—	—	—	—	—	—	—	—

No. of plate from top.	$C_R = 10{,}000$		$C_R = 11{,}000$		$C_R = 12{,}000$		$C_R = 13{,}000$		$C_R = 14{,}000$	
	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %
	91·85	92·57	91·85	92·57	91·85	92·57	91·85	92·57	91·85	92·57
1	91·1	92	91·1	91·95	91·1	91·9	91·1	91·97	91·1	91·95
2	90·4	91·45	90·3	91·4	90·3	91·38	90·2	91·35	90·19	91·3
3	89·4	90·88	89·35	90·75	89·3	90·7	89·2	90·62	89·03	90·55
4	88·2	90·1	88·1	90	88	89·9	87·88	89·73	87·63	89·58
5	86·9	89·1	86·8	89	86·43	88·85	86·2	88·7	85·7	88·4
6	85·2	88·19	84·85	87·95	84	87·5	83·7	87·3	82·5	86·8
7	82·5	86·8	81·8	86·4	80·5	85·65	79·5	85·3	77·35	84·3
8	78·2	84·7	76·7	84·09	73·35	82·8	71	82·5	65·4	80·15
9	69·5	81·5	65·5	80·2	53·05	77·3	44·7	75·35	29·4	70·8
10	44·5	75·3	32·3	72·01	17·5	62·9	12·8	56·65	7·74	45·6
11	14·3	58·9	9·5	50·4	6·15	40·31	5·1	36·3	4·2	32
12	6·5	41·5	5·33	37·3	4·58	33·8	4·13	31·73	3·79	29·85
13	5·4	37·5	4·58	33·7	4·38	32·8	4	31·23	3·7	29·5
14	5·25	37	—	—	—	—	—	—	—	—

	$C_R = 20{,}000$		$C_R = 25{,}000$		$C_R = 30{,}000$		$C_R = 35{,}000$		$C_R = 40{,}000$	
	91·75	92·57	91·75	92·57	91·75	92·57	91·75	92·57	94·75	92·57
1	91·15	92	91·09	92	91·01	91·9	91	91·9	90·9	91·9
2	90·34	91·36	90·05	91·2	90	91·16	89·9	91·16	89·85	91·05
3	89·25	90·6	89·95	90·4	88·9	90·3	88·5	90·15	88·4	90·05
4	87·75	89·5	87·25	89·3	87	89·2	86·5	88·9	86·25	88·7
5	85·6	88·4	84·5	87·6	84·1	87·6	83·1	87	82·5	86·8
6	82·3	86·6	80	85·5	78·4	84·9	76·25	83·9	74·25	83·1
7	75·7	83·7	69·2	81·4	65·25	80·1	54·25	77·6	46	75·7
8	55·7	77·9	33	72·2	23·7	68·2	13·9	58·7	9·55	50·8
9	16·25	61·5	6·75	42·5	4·55	33·75	2·8	24·6	2·2	20
10	4·2	32·25	2·5	22·5	2·15	18·8	1·6	15·5	1·37	13·7
11	2·5	22·6	2·2	19·4	1·77	16·6	1·5	14·75	1·33	13·1

Rectification up to 94·6% wt. = 96·5% vol.

	$C_R = 10{,}000$		$C_R = 12{,}000$		$C_R = 15{,}000$	
30	92·05	92·72	89·55	90·9	77·2	84·2
31	91·98	92·59	88·95	90·5	65·3	80·1
32	91·55	92·5	88·3	90·0	31·5	71·75
33	91·7	92·9	87·5	89·5	7·8	46·2
34	91·98	92·4	86·3	88·8	4·0	31·0
35	91·5	92·17	84·65	87·9	3·2	27·05
36	91·4	92·2	82·05	86·55	3·1	26·45
37	91·3	92·05	77·7	84·44		
38	90·25	91·96	68·8	81·15		
39	90·65	91·6	41·3	79·5		
40	90·98	91·46	12·0	55·45		

TABLE 14 (CHART VI)

Ethyl Alcohol and Water

Alcohol-content of liquid (liq.) and vapour (vap.) on every plate in rectifying columns when vapour containing 94·61% wt. (96·5% vol.) of alcohol is produced with a reflux-heat expenditure C_R ranging from 10,000 to 150,000 kg. cal. for every 10 kg. of alcohol recovered. ($a_e = 10$, $w_e = 0{\cdot}565$).

Rectification up to 94·6% wt. = 96·5% vol. for 10 kg. alcohol.

No. of plate from top.	$C_R = 10{,}000$		$C_R = 12{,}000$		$C_R = 15{,}000$		$C_R = 20{,}000$		$C_R = 30{,}000$	
	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %
	94·5	94·61	94·5	94·61	94·5	94·61	94·5	94·61	94·5	94·61
1	94·48	94·55	94·43	94·58	94·45	94·58	94·46	94·50	99·44	94·48
2	94·40	94·50	94·4	94·48	94·40	94·5	94·3	94·45	94·30	94·42
3	94·33	94·45	94·31	94·44	94·3	94·4	94·2	94·39	94·20	94·37
4	94·28	94·40	94·28	94·4	94·2	94·38	94·1	94·29	94·23	94·13
5	94·16	94·34	94·15	94·32	94·1	94·30	90·02	94·20	94·77	94·10
6	94·10	94·30	94·09	94·23	93·99	94·18	93·9	94·1	93·93	94·09
7	94·03	94·24	93·98	94·19	93·9	94·1	93·8	94·0	93·77	93·95
8	93·97	94·18	93·85	94·01	93·8	94·0	93·7	93·93	93·55	93·84
9	93·95	94·12	93·80	94·03	93·7	93·98	93·50	93·8	93·28	93·6
10	93·90	94·08	93·70	93·93	93·5	93·93	93·29	93·6	93·0	93·35
11	93·85	94·04	93·6	93·85	93·35	93·7	93·03	93·4	92·70	93·1
12	93·80	94·0	93·5	93·80	93·2	93·6	92·69	93·2	92·22	92·8
13	93·75	93·95	93·4	93·70	93·03	93·4	92·48	92·97	91·62	92·45
14	93·70	93·90	93·3	93·63	92·82	93·25	92·09	92·70	91·0	91·9
15	93·6	93·88	93·19	93·53	92·61	93·13	91·7	92·35	90·1	91·29
16	93·5	93·8	93·03	93·4	92·40	92·90	91·29	92·05	89·0	90·5
17	93·45	93·8	92·9	93·3	92·25	92·80	90·7	91·65	87·5	89·55
18	93·33	93·63	92·75	93·2	92·0	92·55	90·05	91·15	85·1	88·1
19	93·28	93·6	92·62	93·1	91·65	92·25	89·17	90·6	81·0	85·95
20	93·2	93·55	92·49	93·0	91·43	92·29	86·8	89·0	71·6	82·2
21	93·1	93·48	92·3	92·85	91·03	91·90	84·5	87·8	39·28	73·85
22	93·0	93·4	92·05	92·75	90·5	91·5	80·55	85·7	8·13	46·4
23	92·9	93·3	91·85	92·49	90·0	91·16	72·0	82·4	2·4	21·43
24	92·8	93·27	91·75	92·4	89·3	90·7	43·75	75·0	1·775	17·18
25	92·75	93·22	91·45	92·2	88·4	90·09	10·59	52·7	1·75	16·5
26	92·58	93·1	91·2	92·0	88·25	89·38	3·495	28·45	1·64	16·0
27	92·55	93·03	90·85	91·8	87·0	89·2	2·665	23·45	—	—
28	92·33	92·83	90·5	91·5	85·23	88·8	2·60	23·0	—	—
29	92·16	92·82	90·0	91·2	82·3	86·63	—	—	—	—
30	92·05	92·72	89·55	90·9	77·2	84·2	—	—	—	—
31	91·98	92·59	88·95	90·5	65·3	80·1	—	—	—	—
32	91·55	92·5	88·3	90·0	31·5	71·75	—	—	—	—
33	91·7	92·4	87·5	89·5	7·8	46·2	—	—	—	—
34	91·68	92·4	86·3	88·8	4·0	31·0	—	—	—	—
35	91·5	92·17	84·65	87·9	3·2	27·05	—	—	—	—
36	91·4	92·2	82·05	86·55	3·1	26·45	—	—	—	—
37	91·3	92·05	77·7	84·44	—	—	—	—	—	—
38	90·25	91·96	68·8	81·15	—	—	—	—	—	—
39	90·65	91·6	41·3	74·5	—	—	—	—	—	—
40	90·48	91·46	12·0	55·45	—	—	—	—	—	—

Rectification up to 94·6% wt. = 96·5% vol. for 10 kg. alcohol.

No. of plate from top.	$C_R = 40{,}000$		$C_R = 50{,}000$		$C_R = 60{,}000$		$C_R = 70{,}000$		$C_R = 80{,}000$	
	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %
	94·5	94·61	94·5	94·61	94·5	94·61	94·5	94·61	94·5	94·61
1	94·43	94·5	94·4	94·5	94·4	94·5	94·4	94·50	94·45	94·5
2	94·35	94·45	94·29	94·45	94·3	94·45	94·3	94·43	94·3	94·4
3	94·2	94·35	94·21	94·35	94·15	94·35	94·12	94·33	94·1	94·33
4	94·02	94·22	94·0	94·20	93·98	94·2	93·9	94·11	93·7	93·95
5	93·9	94·06	93·95	94·03	93·8	93·98	93·7	93·95	93·45	93·79
6	93·79	93·99	93·62	93·90	93·6	93·85	93·45	93·79	93·1	93·5
7	93·66	93·87	93·40	93·70	93·3	93·6	93·1	93·5	92·75	93·15
8	93·4	93·7	93·07	93·5	92·99	93·35	92·65	93·19	92·25	92·8
9	93·13	93·5	92·70	93·19	92·55	93·09	92·30	92·8	91·63	92·3
10	92·73	93·1	92·25	92·8	92·05	92·6	91·75	92·48	90·8	91·7
11	92·33	92·89	91·73	92·4	91·38	92·1	90·98	91·90	89·7	90·99
12	91·95	92·58	91·02	91·9	90·5	91·5	89·9	91·1	88·15	89·9
13	91·45	92·1	89·7	91·2	89·3	90·7	88·45	90·15	85·8	88·4
14	90·6	91·54	88·8	90·3	87·5	89·5	86·60	88·70	81·35	86·1
15	89·5	90·8	86·9	89·1	84·65	87·89	82·75	86·9	70·5	81·85
16	88·9	89·8	83·75	87·4	79·3	85·15	74·5	83·2	30·8	71·5
17	83·05	86·9	77·3	84·3	65·0	80·15	45·5	75·4	4·65	52·15
18	76·1	83·9	57·7	81·5	21·55	66·75	9·01	49·35	1·05	10·88
19	53·73	77·4	15·11	60·1	3·255	27·2	1·58	15·29	0·646	7·28
20	13·3	56·6	2·5	22·7	1·085	11·17	0·79	8·515	0·625	6·92
21	3·4	28·97	1·19	18·3	—	—	—	—	—	—
22	1·40	12·0	1·75	17·5	—	—	—	—	—	—

	$C_R = 90{,}000$		$C_R = 100{,}000$		$C_R = 110{,}000$		$C_R = 130{,}000$		$C_R = 150{,}000$	
	94·5	94·61	94·5	94·61	94·5	94·61	94·5	94·61	94·5	94·61
1	94·4	94·5	94·4	94·5	94·4	94·5	94·4	94·5	94·4	94·5
2	94·3	94·49	94·3	94·49	94·3	94·46	94·3	94·44	94·3	94·43
3	94·2	94·34	94·2	94·33	94·2	94·32	94·2	94·32	94·2	94·31
4	94·04	94·22	93·99	94·25	93·99	94·25	93·98	94·20	93·98	94·19
5	93·9	94·07	93·9	94·07	93·9	94·06	93·87	94·03	93·8	94·0
6	93·69	93·92	93·68	93·90	93·68	93·87	93·63	93·85	93·6	93·83
7	93·37	93·7	93·35	93·7	93·32	93·7	93·30	93·60	93·28	93·6
8	93·0	93·4	93·0	93·39	92·9	93·37	92·9	93·32	92·9	93·31
9	92·8	93·15	92·7	93·0	92·55	93·0	92·5	92·98	92·3	91·8
10	92·35	92·90	92·3	92·8	91·99	92·55	91·85	92·55	91·68	92·3
11	91·53	92·43	91·3	92·35	91·3	92·09	91·0	91·9	90·86	91·8
12	90·95	91·95	90·75	91·7	90·2	91·4	89·8	91·05	89·68	90·95
13	89·9	91·05	89·39	90·8	88·8	90·4	88·15	89·95	87·87	89·8
14	88·2	90·3	87·5	89·5	86·7	89·05	85·45	88·25	85·4	88·2
15	85·7	88·45	84·4	87·7	82·9	86·9	80·5	85·7	80·0	85·6
16	81·2	86·0	77·5	84·4	83·0	83·25	67·95	80·9	66·0	80·28
17	69·9	81·6	54·03	77·5	43·55	75·0	24·5	68·7	21·5	66·69
18	29·45	70·9	12·0	55·55	8·35	45·5	3·205	35·7	2·28	19·55
19	4·32	32·75	1·65	14·0	1·105	11·85	0·621	6·99	0·498	5·59
20	0·9	9·61	0·59	6·70	0·50	5·71	0·4185	4·70	0·346	3·92
21	0·57	6·45	0·5	5·7	0·48	5·22	0·399	4·5	0·36	4·1

TABLE 15

Ethyl Alcohol and Water

Concentrating action of the reflux condenser in the production of 10 kg. alcohol as spirit of 85·76% wt. (90% vol.).

No. of plate from top.	Heat removed in reflux condenser.			
	$C_R = 5{,}000$ kg. cal.		$C_R = 7{,}000$ kg. cal.	
	Liq. %	Vap. %	Liq. %	Vap. %
—	20·1	85·75	14·75	85·75
1	11·66	54·30	10·7	53·0
2	10·0	51·50	7·7	45·0
3	9·8	51·0	7·25	44·17

[For explanation of this Table, see Part II, p. 102].

TABLE 16

Ethyl Alcohol and Water

Number of plates required in rectifying columns in the production of 10 kg. of 92·5% wt. (95% vol.) alcohol from an 8·2% liquid with a heat-expenditure $C_R = 10{,}000$ kg. cal., when heat is abstracted within the column, and when it is not. The columns are protected against loss of heat.

Column with one superimposed reflux condenser. Heat abstracted: $C_R = 10{,}000$ kg. cal. per 10 kg. alcohol recovered in product.		Column with five reflux condensers. Heat abstracted: 1000 kg. cal. in each condenser above plates 1, 3, 5, and $C_R = 5{,}000$ kg. cal. in one condenser above the top plate, per 10 kg. of alcohol in product.			
Vapour	Reflux	Vapour	Reflux	Vapour	Reflux
$a_e = 10$ $w_e = 0·82$ 92·4% — 91·85% R. condenser $C_R = 10{,}000$ kg. cal.	$f_V = 0·0887$ $a_V = 39·5$ $w_V = 3·503$	$a_e = 10$ $w_e = 0·82$ 92·4% — 91·85% R. condenser $C_R = 5{,}000$ kg. cal.	$f_V = 0·0887$ $a_V = 19·765$ $w_V = 1·747$	$a_d = 29·45$ $w_d = 2·694$ 2 91·6% — 90·9%	$f_R = 0·102$ $a_R = 19·23$ $w_R = 1·95$
$a_s = 49·5$ $w_s = 4·32$ 1 92% — 91·1%	$f_R = 0·097$ $a_R = 38·3$ $w_R = 3·715$	$a_s = 29·76$ $w_s = 2·567$ 1 92·05% — 91·25%	$f_R = 0·0963$ $a_R = 19·45$ $w_R = 1·874$	$a_d = 29·23$ $w_d = 2·77$ 3 91·39% — 90·25%	$f_R = 0·108$ $a_R = 18·95$ $w_R = 2·046$

Column with one superimposed reflux condenser. Heat abstracted: C_R = 10,000 kg. cal. per 10 kg. alcohol recovered in product.

Vapour		Reflux
a_d=48·3 w_d= 4·535	**2**	91·45% — 90·4% f_R= 0·1065 a_R=38·1 w_R= 4·05
a_d=48·1 w_d= 4·87	**3**	90·88% — 89·4% f_R= 0·1185 a_R=37·1 w_R= 4·39
a_d=47·1 w_d= 5·21	**4**	90·1% — 88·2% f_R= 0·134 a_R=35·9 w_R= 4·81
a_d=45·9 w_d= 5·63	**5**	89·1% — 86·9% f_R= 0·507 a_R=34·88 w_R= 5·23
a_d=44·88 w_d= 6·05	**6**	88·19% — 85·2% f_R= 0·1730 a_R=33·44 w_R= 5·81
a_d=43·44 w_d= 6·63	**7**	86·8% — 82·5% f_R= 0·212 a_R=31·25 w_R= 6·63

Column with five reflux condensers. Heat abstracted: 1,000 kg. cal. in each condenser above plates 1, 3, 5, and C_R = 5,000 kg. cal. in one condenser above the top plate, per 10 kg. of alcohol in product.

Vapour		Reflux
a_d=28·95 w_d= 2·866	**4**	91% — 89·7% f_R= 0·1136 a_R=18·8 w_R= 2·13
a_d=28·8 w_d= 2·95	**5**	90·7% — 89·5% f_R= 0·1198 a_R=18·5 w_R= 2·216
a_d=28·5 w_d= 3·035	**6**	90·4% — 88·85% f_R= 0·125 a_R=18·3 w_R= 2·28
a_d=28·3 w_d= 3·1	**7**	90·17% — 88·5% f_R= 0·1299 a_R=18·15 w_R= 2·35
a_d=28·15 w_d= 3·17	**8**	89·9% — 88·1% R. condenser C_R=1,000 kg. cal. f_R= 0·135 a_R=21·5 w_R= 2·91
a_d=31·54 w_d= 3·73	**9**	89·4% — 87·2% f_R= 0·146 a_R=21·06 w_R= 3·07

Vapour		Reflux
a_d=31·06 w_d= 3·89	**10**	88·9% — 86·3% f_R= 0·158 a_R=20·61 w_R= 3·25
a_d=30·61 w_d= 4·07	**11**	88·2% — 85·5% f_R= 0·1696 a_R=20·2 w_R= 3·42
a_d=30·2 w_d= 4·24	**12**	87·7% — 84·5% R. condenser C_R=1,000 kg. cal. f_R= 0·1834 a_R=23 w_R= 4·2
a_d=33 w_d= 5·02	**13**	86·8% — 82·5% f_R= 0·212 a_R=21·87 w_R= 4·64
a_d=31·87 w_d= 5·46	**14**	85·3% — 79·6% R. condenser C_R=1,000 kg. cal. f_R= 0·256 a_R=23·2 w_R= 5·93
a_d=33·2 w_d= 6·75	**15**	83·1% — 74% f_R= 0·3574 a_R=20·2 w_R= 7·09

[The figures in bold type refer to the plates in the columns.]

Column with one superimposed reflux condenser. Heat abstracted: C_R = 10,000 kg. cal. per 10 kg. alcohol recovered in product.

Vapour	Reflux
a_d=41·25 w_d= 7·45 8 84·7% — 78·2%	
	f_R= 0·278 a_R=28·09 w_R= 7·81
a_d=38·09 w_d= 8·63 9 81·5% — 69·5%	
	f_R= 0·4389 a_R=22·57 w_R= 9·9
a_d=32·57 w_d=10·72 10 75·3% — 44·5%	
	f_R= 1·247 a_R=11·33 w_R=14·1
a_d=21·33 w_d=14·92 11 58·9% — 14·3%	
	f_R= 5·99 a_R= 2·89 w_R=17·21
a_d=12·89 w_d=18·13 12 41·5% — 6·5%	
	f_R=14·385 a_R= 1·25 w_R=18
a_d=11·25 w_d=18·82 13 37·5% — 5·4%	
	f_R=17·579 a_R= 1·028 w_R=18·01
a_a=11·028 w_a=18·829 14 37% — 5·25%	
	f_B=18·05

Column with five reflux condensers. Heat abstracted: 1,000 kg. cal. in each condenser above plates 1, 3, 5, and C_R = 5,000 kg. cal. in one condenser above the top plate, per 10 kg. of alcohol in product.

Vapour	Reflux	Vapour	Reflux
a_d=30·2 w_d= 7·91 16 79·3% — 62%		a_d=11·923 w_d=18·52 19 46·5% — 8·1%	
R. condenser C_R=1,000 kg. cal.	f_R= 0·6129 a_R=16·72 w_R=10·23		f_R=11·35 a_R= 1·568 w_R=17·93
a_d=26·79 w_d=11·05 17 70·8% — 29%		a_d=11·57 w_d=18·75 20 38·5% — 5·6%	
	f_R= 2·445 a_R= 5·886 w_R=14·41		f_R=16·857 a_R= 1·071 w_R=18
a_d=15·886 w_d=15·24 18 51% — 9·8%		a_a=11·07 w_a=18·82 21 37% — 5·25%	
R. condenser C_R=1,000 kg. cal.	f_R= 9·204 a_R= 1·923 w_R=17·7		f_B=18·05

TABLE 17

Ethyl Alcohol and Water

Comparison of the results obtained when a residual vapour of 80% wt. is produced from 100 kg. of a 50% mixture of alcohol and water vapours by fractional condensation in six stages and in two stages.

	Vapour			Condensate			Vapour			Condensate			
	kg.	% wt.	Contents	kg.	% wt.	Contents	kg.	% wt.	Contents	kg.	% wt.	Contents	
100 kg. alcohol-water vapour of 50% (wt.)	100	50	$a_d=50$ $w_d=50$	—	—	—	100	50	$a_d=50$ $w_d=50$	—	—	—	Reflux condenser.
1. gave after one partial condensation	88·44	55	$a_e=48{\cdot}64$ $w_e=39{\cdot}80$	11·55	11·75	$a_R=1{\cdot}35$ $w_R=10{\cdot}20$	53·35	70	$a_e=37{\cdot}35$ $w_e=16{\cdot}00$	46·60	27	$a_R=12{\cdot}60$ $w_R=34{\cdot}00$	
2. gave after residual vapour was partly condensed	78·63	60	$a_e=47{\cdot}19$ $w_e=31{\cdot}44$	9·82	15·0	$a_R=1{\cdot}46$ $w_R=8{\cdot}36$	17·73	80	$a_e=14{\cdot}18$ $w_e=3{\cdot}55$	35·64	65	$a_R=23{\cdot}17$ $w_R=12{\cdot}47$	
3. ditto	69·61	65	$a_e=45{\cdot}33$ $w_e=24{\cdot}38$	8·22	19·5	$a_R=1{\cdot}16$ $w_R=7{\cdot}06$							
4. ditto	61·60	70	$a_e=43{\cdot}10$ $w_e=18{\cdot}50$	8·11	27·0	$a_R=2{\cdot}23$ $w_R=5{\cdot}88$							
5. ditto	51·71	75	$a_e=38{\cdot}79$ $w_e=12{\cdot}92$	7·89	43·5	$a_R=4{\cdot}21$ $w_R=3{\cdot}68$							
6. ditto	34·46	80	$a_e=27{\cdot}58$ $w_e=6{\cdot}88$	17·30	65·0	$a_R=11{\cdot}21$ $w_R=6{\cdot}09$							

Therefore, 100 kg. alcohol-water vapour of 50% wt. give by fractional condensation

in 6 stages 34·46 kg. of 80% wt. alcohol-water vapour.
in 2 „ 17·73 „ „ „ „

After each condensation the residual vapour is separated from the liquid condensate:

$$\frac{w_e + w_R}{a_e + a_R} = \frac{a_e f_e + a_R f_R}{a_e + a_R} = f_d$$

$$a_e = \frac{a_R(f_R - f_d)}{f_d - f_e} \qquad a_R = a_d - a_e$$

$$a_e = \frac{a_d(f_R - f_d)}{f_R - f_e} \qquad w_e = a_e f_e$$

Since $a_d + w_d$ is known, f_d is also known; f_e is required; f_R is known.

TABLE 18 (CHART V)

Ethyl Alcohol and Water

The heat C_a required in *boiling-columns* to separate 100 kg. of water from mixtures containing 85—0·5% wt. (89·4—0·62% vol.) of alcohol (or the heat required, per 100 kg. of spent wash, to raise the alcohol-content of the liquid from 0·01% to 85%.).

Alcohol-content		For 100 kg. spent wash C_a kg. cal.	Alcohol-content		For 100 kg. spent wash C_a kg. cal.	Alcohol-content		For 100 kg. spent wash C_a kg. cal.
Liquid wt. %	Vapour wt. %		Liquid wt. %	Vapour wt. %		Liquid wt. %	Vapour wt. %	
85	88·0	695,800	55	77·8	67,500	25	69·0	17,600
84	87·60	593,400	54	77·5	64,500	24	68·4	16,900
83	87·0	515,500	53	77·3	61,200	23	67·7	16,200
82	86·50	454,900	52	77·1	58,200	22	67·0	15,800
81	85·95	413,100	51	76·9	55,500	21	66·3	14,800
80	85·50	368,600	50	76·7	53,000	20	65·5	14,100
79	85·0	337,200	49	76·4	50,600	19	64·5	13,600
78	84·6	317,700	48	76·2	48,300	18	63·5	13,100
77	84·20	292,100	47	75·9	46,400	17	62·4	12,400
76	83·80	252,900	46	75·7	44,400	16	61·2	11,900
75	83·50	230,300	45	75·4	42,500	15	60·0	11,400
74	83·1	213,000	44	75·2	40,700	14	58·6	10,900
73	82·7	199,100	43	74·9	39,000	13	57·0	10,400
72	82·4	183,300	42	74·6	37,500	12	55·5	9,800
71	82·0	171,600	41	74·3	35,900	11	53·6	9,300
70	81·7	159,400	40	74·0	34,550	10	51·6	8,900
69	81·3	150,400	39	73·8	33,000	9	49·2	8,440
68	80·9	141,800	38	73·6	31,400	8	46·3	8,070
67	80·6	133,200	37	73·4	30,000	7	43·3	7,660
66	80·30	125,490	36	73·1	28,800	6	39·8	7,250
65	80·0	118,000	35	72·8	27,500	5	36·0	6,810
64	79·8	110,300	34	72·5	26,300	4	31·2	6,420
63	79·6	104,000	33	72·2	25,200	3	26·3	5,860
62	79·3	101,100	32	71·9	24,100	2	18·5	5,700
61	79·1	95,600	31	71·6	23,000	1	10·5	5,290
60	78·9	90,100	30	71·2	22,100	0·5	5·7	5,090
59	78·7	85,300	29	70·8	21,100	0·3	3·36	5,400
58	78·4	81,000	28	70·5	20,100	0·1	1·10	5,410
57	78·2	74,806	27	70·0	19,200	0·05	0·55	5,420
56	78·0	70,900	26	69·5	18,500	0·01	0·11	5,430

In Chart V, the values of C_a are only one-tenth of those given in Table 18, because they refer to 10 kg., and not 100 kg., of separated water.

TABLE 19 (CHART VII)

Ethyl Alcohol and Water

Content of alcohol in the liquid (L) and the vapour (V) on each of the plates of a *boiling-column* when the heat-expenditure C_a ranges from 6,000 to 450,000 kg. cal. for every 100 kg. of spent wash.

No. of plate from base.	Heat-expenditure C_a for 100 kg. of spent wash.									
	6000 kg. cal.		7000 kg. cal.		7500 kg. cal.		8000 kg. cal.		9000 kg. cal.	
	L. %	V. %	L. %	V. %	L. %	V. %	L. %	V. %	L. %	V. %
27	0·129	1·47	—	—	—	—	—	—	—	—
26	0·121	1·33	—	—	6·15	40·12	—	—	—	—
25	0·112	1·22	4·05	31·4	5·95	39·69	7·6	45·25	—	—
24	0·1028	1·12	3·9	30·5	5·6	38·60	7·5	45·0	—	—
23	0·095	1·02	3·51	28·72	5·2	36·79	7·16	43·9	—	—
22	0·086	0·95	3·1	26·51	4·75	34·7	6·845	42·8	—	—
21	0·079	0·86	2·7	23·7	4·40	33·0	6·445	41·4	9·89	51·6
20	0·071	0·79	2·3	20·49	3·89	30·3	5·83	39·33	9·83	51·5
19	0·065	0·705	2·0	18·43	3·39	27·4	5·075	36·4	9·61	50·65
18	0·0595	0·65	1·5	15·69	2·61	23·30	4·29	32·65	9·32	49·75
17	0·054	0·60	1·1	12·25	2·18	19·42	3·39	28·25	8·77	48·55
16	0·048	0·55	0·9	9·70	1·76	16·49	2·61	23·05	8·0	46·3
15	0·044	0·48	0·65	7·50	1·35	13·5	1·9	18·0	6·94	43·1
14	0·04	0·44	0·5	5·62	0·99	10·42	1·32	13·7	5·72	38·73
13	0·0365	0·40	0·4	4·35	0·692	7·70	0·95	9·8	4·40	33·1
12	0·033	0·36	0·29	3·499	0·48	5·35	0·63	7·0	3·10	26·52
11	0·028	0·31	0·2	2·385	0·34	3·80	0·414	4·75	2·19	19·45
10	0·0235	0·28	0·19	1·855	0·29	2·85	0·273	3·19	1·35	14·09
9	0·023	0·25	0·17	1·49	0·195	2·10	0·180	2·10	0·84	9·05
8	0·0205	0·230	0·19	1·15	0·14	1·60	0·120	1·42	0·528	5·77
7	0·0195	0·210	0·088	0·987	0·11	1·15	0·089	0·92	0·195	2·29
6	0·0175	0·190	0·065	0·665	0·08	0·899	0·063	0·701	0·119	1·42
5	0·016	0·175	0·05	0·55	0·06	0·66	0·045	0·50	0·079	0·88
4	0·015	0·162	0·039	0·41	0·04	0·51	0·032	0·37	0·051	0·55
3	0·0135	0·149	0·03	0·329	0·038	0·439	0·0225	0·25	0·033	0·336
2	0·012	0·135	0·018	0·18	0·029	0·19	0·016	0·179	0·021	0·225
1	0·0109	0·12	0·013	0·13	0·014	0·14	0·014	0·118	0·0165	0·149
	0·01	0·11	0·01	0·11	0·01	0·111	0·01	0·1	0·01	0·1

No. of plate from base.	Heat-expenditure C_a for 100 kg. of spent wash.							
	10,000 kg. cal.		12,000 kg. cal.		15,000 kg. cal.		20,000 kg. cal.	
	L. %	V. %	L. %	V. %	L. %	V. %	L. %	V. %
21	12·25	55·9	—	—	—	—	—	—
20	12·22	55·7	—	—	—	—	—	—
19	11·95	55·45	—	—	—	—	—	—
18	11·73	54·95	—	—	—	—	—	—
17	11·16	54·05	16·12	61·3	—	—	—	—
16	10·3	52·25	15·85	60·97	—	—	—	—
15	9·0	51·0	15·58	60·6	—	—	—	—
14	9·0	48·0	14·89	59·83	21·5	66·5	—	—
13	6·75	42·5	13·74	57·9	21·0	66·3	—	—
12	4·899	35·4	11·65	54·75	20·4	65·75	—	—
11	3·19	26·85	8·69	48·25	19·1	64·5	—	—
10	2·066	18·47	5·68	38·6	16·21	61·55	28·0	70·5
9	1·15	12·02	3·175	26·8	11·70	54·95	26·5	69·7
8	0·63	6·99	1·70	16·15	9·55	50·7	23·39	68·0
7	0·34	3·91	0·77	9·20	3·30	27·2	17·1	62·4
6	0·20	2·19	0·36	4·10	1·35	13·9	9·94	49·25
5	0·119	1·29	0·18	1·98	0·535	6·30	2·95	25·5
4	0·069	0·766	0·091	1·0	0·229	2·40	1·0	10·4
3	0·041	0·45	0·060	0·65	0·095	1·03	0·2069	3·03
2	0·0235	0·26	0·033	0·355	0·0495	0·445	0·088	0·97
1	0·017	1·513	0·020	0·18	0·0205	0·215	0·0295	0·324
	0·01	0·1	0·01	0·1	0·01	0·1	0·01	0·1
	25,000 kg. cal.		30,000 kg. cal.		40,000 kg. cal.		65,000 kg. cal.	
10	32·4	72·1	—	—	—	—	—	—
9	31·95	71·9	37·0	73·4	44·0	75·2	54·5	77·6
8	30·55	71·4	36·1	73·1	43·1	74·95	54·0	77·5
7	24·2	68·6	31·75	71·8	41·85	74·6	53·45	77·4
6	13·59	57·8	20·29	64·4	34·2	72·59	50·0	76·7
5	5·0	36·0	11·0	44·35	17·1	62·6	34·9	72·8
4	1·53	14·88	2·39	20·3	4·9	25·2	11·21	54·0
3	0·414	4·78	0·581	6·43	1·05	11·0	2·18	19·4
2	0·108	1·3	0·149	1·62	0·216	2·43	0·358	3·92
1	0·0348	0·38	0·0391	0·429	0·0467	0·510	0·0601	0·657
	0·01	0·1	0·01	0·1	0·01	0·1	0·01	0·1
	120,000 kg. cal.		150,000 kg. cal.		225,000 kg. cal.		450,000 kg. cal.	
8	62·8	79·5	68·7	81·2	79·5	83·3	80·7	85·8
7	61·85	79·2	68·1	80·95	73·59	83·0	79·8	85·4
6	59·79	78·9	66·43	80·35	71·5	82·2	77·5	84·4
5	50·0	76·7	58·95	78·7	39·41	80·0	70·9	81·9
4	20·8	65·95	29·30	70·9	37·2	73·2	45·5	75·4
3	3·74	30·69	5·70	37·5	7·1	43·52	9·1	49·28
2	0·512	5·65	0·655	7·24	0·80	8·70	1·0	10·0
1	0·0704	0·765	0·082	0·88	0·089	0·99	0·099	1·1
	0·01	0·1	0·01	0·1	0·01	0·1	0·01	0·1

TABLE 20 (CHART VIII). Ethyl Alcohol and Water

Heat-quantities (kg. cal.) needed to raise 100 kg. of alcohol-water mixtures of from 0·5 to 80% strength to boiling-temperature, and to raise their alcohol-content to 11–82% in stages of 1%.

Initial alcohol-content of mixture. (Alcohol wt. %.)	Upper line: Alcohol-content on plate M. Lower line: Heat required to raise temp. of mixture to boiling-pt.												
0·5 (lowest curve)	%	1·0	1·5	2	3	4	5	6	7	8	9	10	11
	kg. cal.	2875	3902	4507	5189	5808	6840	7411	7980	8892	9104	9310	9530
1	%	1·5	2	3	4	5	6	7	8	9	10	11	12
	kg. cal.	1866	2975	3906	4865	5448	6042	6555	7061	7502	8010	8450	8985
1·5	%	2	2·5	3	4	5	6	7	8	9	10	11	12
	kg. cal.	1512	2719	3181	4125	5297	6075	6636	7640	8047	8330	8630	9015
2	%	2·5	3	4	5	6	7	8	9	10	11	12	13
	kg. cal.	1166	2150	3210	4086	4832	5472	6052	6565	7120	7609	8141	8800
3	%	4	5	6	7	8	9	10	11	12	13	14	15
	kg. cal.	1604	2718	3609	4368	5040	5622	6222	6660	7100	7998	8564	8800
5	%	6	7	8	9	10	11	12	13	14	15	16	17
	kg. cal.	1133	2186	3019	3754	4450	5065	5710	6395	7000	7600	8280	8750
7	%	8	9	10	11	12	13	14	15	16	17	18	19
	kg. cal.	1008	1876	2663	3381	4333	5026	5698	6342	6930	7294	7920	8570
8	%	9	10	11	12	13	14	15	16	17	18	19	20
	kg. cal.	950	1750	2585	3270	4160	4800	5480	6200	6770	7180	7860	8530
10	%	11	12	13	14	15	16	17	18	19	20	21	22
	kg. cal.	845	1643	2400	3114	3799	4462	5105	5777	6440	7000	7752	8454
15	%	16	17	18	19	20	21	22	23	24	25	26	27
	kg. cal.	743	1458	2166	2862	3525	4228	4930	5634	6300	7035	7852	8532
20	%	21	22	23	24	25	26	27	28	29	30	31	—
	kg. cal.	707	1401	2100	2800	3590	4268	4978	5744	6514	7368	8161	—
25	%	26	27	28	29	30	31	32	33	34	35	36	—
	kg. cal.	712	1422	2154	3000	3684	4450	5217	6109	6962	7857	8799	—
30	%	31	32	33	34	35	36	37	38	39	40	—	—
	kg. cal.	742	1503	2290	3093	3928	4800	5678	6609	7611	8624	—	—
35	%	36	37	38	39	40	41	42	43	44	—	—	—
	kg. cal.	799	1661	2478	3374	4312	5250	6247	7255	8337	—	—	—
40	%	41	42	43	44	45	46	47	48	—	—	—	—
	kg. cal.	876	1775	2768	3700	4726	5790	6908	8150	—	—	—	—
50	%	51	52	53	54	55	56	—	—	—	—	—	—
	kg. cal.	1087	2237	3463	4777	6135	7595	—	—	—	—	—	—
60	%	61	62	63	64	65	—	—	—	—	—	—	—
	kg. cal.	1528	3175	4954	6882	9000	—	—	—	—	—	—	—
70	%	71	72	73	—	—	—	—	—	—	—	—	—
	kg. cal.	2414	5091	8160	—	—	—	—	—	—	—	—	—
80 (top curve)	%	81	82	—	—	—	—	—	—	—	—	—	—
	kg. cal.	5426	8024	—	—	—	—	—	—	—	—	—	—

TABLE 21 (CHART II)

Ethyl Alcohol and Water

A liquid alcohol–water mixture $a + w$ is vaporised in stages in such a way that each residual liquid $a_R + w_R$ is 1% weaker than the previous liquid. f_{dm} is the mean ratio of the vapours from $a + w$ and $a_R + w_R$.

$$f_{dm} = \frac{w_{dm}}{a_{dm}}. \quad a_d = \frac{a(f_R - f)}{f_R - f_{dm}}. \quad a_R = \frac{a(f - f_{dm})}{f_R - f_{dm}}.$$

Initial liquid contains	Residual liquid contains	Mean ratio of vapours	Alcohol in each residual liquid if before vaporisation $a = 1$. (In each line $a = 1$, hence $a_R = 1 - a_d$)	Water in each residual liquid if before vaporisation $a = 1$. (In each line $a = 1$, hence $a_R = 1 - a_d$)	Residual liquid (In each line $a = 1$, hence $a_R = 1 - a_d$)	Residual liquid for series of 10 stages (only in the first line of each series is $a = 1$; in each subsequent line a is smaller by a_d) $a_R + w_R$		Residual liquid from 50% to end (only in the first line of all is $a = 1$; it then diminishes progressively by a_d) $a_R + w_R$	
a %	a_R %	f_{dm}	a_R kg.	w_R kg.	$a_R + w_R$ kg.	$a + w = 2$ kg.	% of wt. $a + w = 2$	kg.	% of wt. $a + w = 2$
50	49	0·3042	0·940	0·9776	1·917	1·917	95·85	—	95·85
49	48	0·3093	0·943	1·043	1·986	1·862	93·10	—	93·10
48	47	0·3149	0·944	1·060	2·004	1·773	88·65	—	88·65
47	46	0·3192	0·945	1·108	2·053	1·720	86·00	—	86·00
46	45	0·3237	0·945	1·152	2·097	1·653	83·65	—	83·65
45	44	0·3281	0·946	1·204	2·150	1·608	80·40	—	80·40
44	43	0·3324	0·946	1·250	2·196	1·550	77·50	—	77·50
43	42	0·3378	0·947	1·306	2·253	1·506	75·30	—	75·30
42	41	0·3432	0·948	1·363	2·311	1·463	73·15	—	73·15
41	40	0·3487	0·948	1·422	2·370	1·422	71·10	—	71·10
						$a + w = 2·5$	% of wt. $a + w = 2·5$		
40	39	0·3532	0·949	1·484	2·433	2·433	97·32	1·384	69·20
39	38	0·3568	0·948	1·546	2·494	2·366	94·64	1·346	67·30
38	37	0·3605	0·947	1·610	2·557	2·303	92·12(I)	1·301	65·05
37	36	0·3652	0·947	1·683	2·630	2·240	89·60	1·274	63·70
36	35	0·3708	0·947	1·757	2·704	2·178	87·12	1·238	61·90
35	34	0·3765	0·946	1·836	2·782	2·125	85·00	1·209	60·45
34	33	0·3822	0·945	1·918	2·863	2·067	82·68	1·176	58·80
33	32	0·3879	0·944	2·005	2·949	2·014	80·56	1·144	57·20
32	31	0·3938	0·944	2·100	3·044	1·963	78·52	1·117	55·85
31	30	0·4006	0·943	2·200	3·143	1·912	76·48	1·087	54·35
						$a + w = 3·333$	% of wt. $a + w = 3·333$		
30	29	0·4084	0·940	2·300	3·240	3·240	97·20	1·058	52·90
29	28	0·4155	0·940	2·416	3·356	3·155	94·65(II)	1·031	51·35
28	27	0·4235	0·940	2·540	3·480	3·074	92·22	1·002	50·10

Initial liquid contains	Residual liquid contains	Mean ratio of vapours.	Alcohol in each residual liquid if before vaporisation $a = 1$.	Water in each residual liquid if before vaporisation $a = 1$.	Residual liquid (In each line $a = 1$, hence $a_R = 1 - a_d$)	Residual liquid for series of 10 stages (only in the first line of each series is $a = 1$; in each subsequent line a is smaller by a_d) $a_R + w_R$		Residual liquid from 50% to end (only in the first line of all is $a = 1$; it then diminishes progressively by a_d) $a_R + w_R$	
a %	a_R %	f_{dm}	a_R kg.	w_R kg.	$a_R + w_R$ kg.	$a+w$ =2 kg.	% of wt. $a + w = 2$	kg.	% of wt. $a+w=2$
27	26	0·4338	0·940	2·730	3·670	3·064	91·92	0·998	49·90
26	25	0·4442	0·940	2·820	3·760	2·951	88·53	0·963	48·15
25	24	0·4557	0·939	2·970	3·909	2·885	86·55	0·940	47·00
24	23	0·4695	0·939	3·140	4·079	2·826	84·78	0·921	47·05
23	22	0·4848	0·935	3·310	4·245	2·763	82·89	0·900	45·00
22	21	0·5004	0·933	3·510	4·443	2·699	80·97(II)	0·881	44·05
21	20	0·5175	0·929	3·716	4·645	2·636	79·08	0 860	43·00
						$a + w$ = 5	% of wt. $a + w = 5$		
20	19	0·5386	0·928	3·954	4·882	4·882	97·64	0·839	41·95
19	18	0·5626	0·925	4·213	5·138	4·767	95·34	0·819	40·95
18	17	0·5887	0·924	4·510	5·434	4·667	93·34	0·802	40·10
17	16	0·6183	0·920	4·830	5·750	4·559	91·18(III)	0·783	39·15
16	15	0·6504	0·915	5·182	6·097	4·445	88·90	0·764	38·20
15	14	0·6766	0·913	5·605	6·518	4·348	86·96	0·747	37·35
14	13	0·7305	0·908	6·076	6·984	4·256	85·12	0·732	36·60
13	12	0·7781	0·904	6·629	7·533	4·169	83·38	0·716	35·80
12	11	0·8338	0·896	7·249	8·145	4·073	81·46	0·700	35·00
11	10	0·9019	0·884	7·956	8·840	3·962	79·24	0·681	34·05
						$a + w$ = 10	% of wt. $a + w = 10$		
10	9	0·9853	0·881	8·898	9·779	9·779	97·79	0·667	33·35
9	8	1·0962	0·874	10·050	10·924	9·602	96·02	0·655	32·75
8	7	1·2347	0·852	11·300	12·152	9·320	93·20	0·636	31·80
7	6	1·4111	0·835	13·070	13·905	9·080	90·80	0·619	30·95
6	5	1·6452	0·806	15·310	16·116	8·780	87·80(IV)	0·599	29·95
5	4	1·9925	0·772	18·570	19·342	8·490	84·90	0·579	28·95
4	3	2·5037	0·719	23·220	23·939	8·130	81·30	0·554	27·70
3	2	4·1038	0·628	30·770	31·398	7·650	76·50	0·522	26·10
2	1	6·4646	0·459	45·440	45·899	7·020	70·20	0·479	23·95
1	0·5	12·534	0·457	90·900	91·357	6·418	64·18	0·438	21·90
0·5	0·25	26·474	0·452	188·000	188·452	6·040	60·40	0·412	20·60
0·25	0·150	51·690	0·520	389·40	389·920	5·650	56·50	0·385	19·25
0·150	0·100	78·443	0·646	645·00	645·640	5·496	54·96	0·374	18·70
0·100	0·050	135·365	0·464	928·00	928·464	5·104	51·04	0·348	17·40
0·050	0·010	544·450	0·1189	1189·00	1189·1189	3·032	30·32	0·207	10·35

TABLE 22 (CHART II). Ethyl Alcohol and Water

An alcohol–water vapour-mixture $a_s + w_s = 1{\cdot}666$ kg. (60–92%), in which $a_s = 1$, is condensed in stages, each residual vapour $a_e + w_e$ being 1% richer than the previous one. f_{Rm} is the mean ratio of the liquid from which $a_s + w_s$ and $a_e + w_e$ were formed. $a_e = \dfrac{a_s(f_{Rm} - f_s)}{f_{Rm} - f_e}$.

Initial vapour contains	Residual vapour contains	Mean ratio of liquid.	Alcohol in residual vapour of each stage, when $a_s = 1$ before vaporising.	Water in residual vapour of each stage, when $a_s = 1$ before vaporising.	Residual vapour of each stage. $a_e + w_e$		Residual vapour after n vaporisations. $a_0 + w_e$	
a_s %	a_e %	f_{Rm}	a_e kg.	w_e kg.	kg.	%	kg.	%
60	61	5·458	0·994	0·630	1·624	97·8	1·624	97·8
61	62	5·137	0·994	0·608	1·602	97·8	1·590	95·4
62	63	4·869	0·994	0·584	1·578	97·8	1·557	93·4
63	64	4·559	0·994	0·557	1·551	97·8	1·522	91·2
64	65	4·267	0·993	0·534	1·527	97·8	1·490	89·4
65	66	4·003	0·993	0·512	1·505	97·8	1·458	87·3
66	67	3·712	0·993	0·490	1·483	97·7	1·426	85·5
67	68	3·419	0·993	0·368	1·461	97·7	1·394	83·6
68	69	3·196	0·992	0·445	1·437	97·6	1·362	81·6
69	70	2·852	0·992	0·425	1·417	97·6	1·332	79·8
70	71	2·547	0·991	0·405	1·397	97·4	1·302	78·0
71	72	2·257	0·990	0·385	1·375	97·4	1·272	76·3
72	73	1·957	0·989	0·365	1·354	97·4	1·240	74·4
73	74	1·659	0·986	0·346	1·332	97·4	1·204	72·3
74	75	1·399	0·982	0·327	1·309	97·4	1·168	70·0
75	76	1·199	0·978	0·307	1·285	97·1	1·127	67·7
76	77	1·031	0·975	0·291	1·266	96·9	1·087	65·2
77	78	0·864	0·972	0·274	1·246	95·7	1·041	62·4
78	79	0·719	0·965	0·255	1·220	95·2	0·991	59·5
79	80	0·596	0·956	0·239	1·195	94·4	0·938	56·3
80	81	0·499	0·940	0·223	1·163	93·40	0·871	52·3
81	82	0·434	0·928	0·204	1·132	91·40	0·797	47·8
82	83	0·380	0·915	0·186	1·101	90·0	0·719	43·1
83	84	0·329	0·905	0·173	1·078	89·20	0·643	38·6
84	85	0·2865	0·872	0·154	1·026	86·0	0·558	33·5
85	86	0·2494	0·839	0·137	0·976	82·86	0·461	27·7
86	87	0·219	0·809	0·121	0·930	80·16	0·368	22·1
87	88	0·190	0·758	0·103	0·861	74·90	0·276	16·6
88	89	0·1643	0·684	0·085	0·769	67·67	0·187	11·2
89	90	0·141	0·600	0·064	0·664	58·87	0·127	7·62
90	91	0·122	0·564	0·056	0·620	46·80	0·0618	3·71
91	92	0·105	0·2775	0·024	0·301	27·36	0·0169	1·014
92	93	0·089	0·14284	0·011	0·153	14·07	0·00238	0·143

TABLE 23 (CHART III)

Methyl Alcohol and Water $\alpha = 255$, $\beta = 550$

Methyl-alcohol content of liquid mixtures of methyl alcohol and water and of the vapours rising therefrom. Ratios of liquids $\frac{w}{a} = f$ and of vapours $\frac{w_d}{a_d} = f_d$.

Values of $\frac{\alpha + f\beta}{f - f_d}$ and $\frac{\alpha + f_d\beta}{f - f_d}$.

Percentage figures according to H. Bergström, amplified by the author.

Methyl alcohol in liquid. %	f	Methyl alcohol in vapour. %	f_d	$\frac{\alpha + f \cdot \beta}{f - f_d}$	$\frac{\alpha + f_d\beta}{f - f_d}$
100	0	100	0		
99	0·0101	99·66	0·00340	3,8888	38,327
98	0·0204	99·32	0·00687	19,720	19,703
97·06	0·0303	99	0·0101	13,449	12,896
97	0·0309	98·980	0·0104	13,268	12,717
96	0·0417	98·640	0·0137	9,960	9,393
95	0·0525	98·3	0·0173	8·066	7,500
94·1625	0·0619	98	0·0204	6,965	6,414
94	0·0638	97·941	0·0210	6,778	6,268
93	0·0752	97·581	0·0257	5,785	5,434
92	0·0869	97·22	0·0288	5,212	4,661
91·3875	0·0939	97	0·0309	4,867	4,317
91	0·099	96·851	0·0324	4,647	4,096
90	0·111	96·5	0·0364	4,236	3,686
89	0·123	96·149	0·0406	3,916	3,365
88·5325	0·1299	96	0·0417	3,737	3,146
88	0·136	95·755	0·0442	3,594	3,039
87	0·149	95·415	0·0483	3,363	2,804
86	0·160	95·076	0·0518	3,178	2,622
85·587	0·1687	95	0·0525	2,995	2,447
85	0·176	94·8	0·0546	2,951	2,346
84	0·190	94·445	0·0589	2,747	2,190
83	0·205	94·090	0·0627	2,580	2,035
82·775	0·2085	94	0·0638	2,557	2,006
82	0·219	93·727	0·0674	2,483	1·933
81	0·234	93·364	0·0700	2,341	1,789
80	0·250	93	0·0752	2,247	1,593
79	0·266	92·68	0·0790	2,143	1,588
78	0·282	92·36	0·0825	2,050	1,500
77	0·2987	92·04	0·0867	2,069	1,500
76·875	0·3007	92	0·0869	1,964	1,417
76	0·3159	91·720	0·0903	1,899	1,351
75	0·3333	91·4	0·00937	1,830	1,279

Methyl alcohol in liquid. %	f	Methyl alcohol in vapour. %	f_a	$\frac{\alpha + f \cdot \beta}{f - f_a}$	$\frac{\alpha + f_a\beta}{f - f_a}$
74	0·352	91·040	0·0986	1770	1218
73·886	0·3626	91	0·099	1724	1172
73	0·370	90·687	0·1025	1716	1167
72	0·389	90·323	0·107	1663	1113·5
71·111	0·4075	90	0·111	1615	1065
71	0·409	89·966	0·111	1606	1060
70	0·429	89·6	0·1165	1568	1019·2
69	0·449	89·24	0·121	1530	978·7
68·330	0·462	89	0·123	1502	949·9
68	0·472	88·884	0·125	1484	933·8
67	0·489	88·524	0·1297	1456	905·6
66	0·515	88·164	0·131	1400	851·5
65·533	0·527	88	0·136	1393	843·8
65	0·538	87·8	0·139	1380	759·7
64	0·563	87·524	0·142	1342	790·8
63	0·587	87·164	0·148	1326	765·4
62·775	0·592	87	0·149	1310	760·6
62	0·613	86·72	0·153	1285	737·0
61	0·639	86·36	0·158	1259	711·0
60	0·666	86	0·162	1230	682·6
59	0·695	85·67	0·168	1208	658·9
58	0·724	85·33	0·172	1183	633·2
57·059	0·751	85	0·176	1183	612·7
57	0·754	84·999	0·177	1161	610
56	0·785	84·657	0·182	1138	588·6
55	0·818	84·3	0·186	1115	565·8
54·25	0·842	84	0·191	1103	552·9
54	0·851	83·9	0·192	1097	548
53	0·887	83·50	0·198	1077	528·1
52	0·923	83·1	0·203	1058	509·3
51·75	0·931	83	0·205	1056	506
51	0·961	82·7	0·209	1043	492
50	1·000	82·3	0·216	1027	477
49·3175	1·029	82	0·219	1013	463
49	1·041	81·882	0·221	1009	458·3
48	1·082	81·440	0·228	995	444·9
47·045	1·127	81	0·234	994	436·2
48	1·128	80·7	0·239	987	434·2
46	1·174	80·4	0·243	966·7	407·7
45	1·222	80·1	0·249	952·9	402·9
44·78	1·234	80	0·250	948·6	398·2
44	1·273	79·64	0·257	949·8	393·8
43	1·326	79·18	0·262	978·0	375·0
42·607	1·349	79	0·266	920·2	370·1
42	1·380	78·72	0·270	913·5	364·0

Methyl alcohol in liquid. %	f	Methyl alcohol in vapour. %	f_d	$\frac{\alpha + f \cdot \beta}{f - f_d}$	$\frac{\alpha + f_d\beta}{f - f_d}$
41	1·439	78·26	0·278	900·0	350·9
40·435	1·477	78	0·282	893	343·2
40	1·500	77·8	0·286	891	339·8
39	1·564	77·2	0·296	881	330·0
38·4	1·601	77	0·299	874·4	322·6
38	1·630	76·7	0·303	868·4	318·5
37	1·703	76·2	0·312	857·2	306·4
36·4	1·749	76	0·316	851·0	299·3
36	1·778	75·8	0·319	845·2	294·7
35	1·857	75·3	0·328	834·6	284·5
34·696	1·887	75	0·333	831·8	281·8
34	1·941	74·94	0·345	828·5	279·8
33	2·033	74·28	0·347	810·1	263·7
32·931	2·039	74	0·352	804	265·0
32	2·124	73·62	0·3587	805	255·8
31·166	2·209	73	0·370	801	249·6
31	2·225	72·96	0·372	799	248·1
30	2·333	72·3	0·382	788·7	238·5
29·571	2·387	72	0·389	783·9	234·0
29	2·449	71·6	0·398	781·4	230·2
28·143	2·548	71	0·409	775·2	224·6
28	2·571	70·9	0·410	772·5	222·2
27	2·704	70·2	0·423	764·0	214·0
26·714	2·749	70	0·429	761·6	211·6
26	2·847	69·5	0·439	755·7	205·6
25·286	2·959	69	0·449	749·9	200·0
25	3·000	68·8	0·452	748·6	197·3
24·2	3·132	68	0·470	743·1	193·2
24	3·167	67·8	0·473	742·6	191·2
23·2	3·310	67	0·489	735·9	185·8
23	3·348	66·8	0·498	731·7	184·5
22·2	3·501	66	0·515	730·5	180·2
22	3·542	65·8	0·520	729·4	179·2
21·2	3·719	65	0·538	724·4	173·2
21	3·762	64·8	0·542	721·6	172·3
20·2	3·949	64	0·563	717·1	166·6
20	4·000	63·8	0·568	715·3	165·4
19·4118	4·166	63	0·587	730·8	165·9
19	4·2661	62·44	0·6004	709·6	159·6
18·677	4·359	62	0·613	708·2	158·0
18	4·550	61·08	0·638	705·1	154·9
17·941	4·587	61	0·639	703·7	153·5
17·206	4·811	60	0·666	699·6	150·0
17	4·882	59·72	0·677	699·9	149·1
16·471	5·079	59	0·693	694·9	147·5

Methyl alcohol in liquid. %	f	Methyl alcohol in vapour. %	f_d	$\frac{\alpha + f \cdot \beta}{f - f_d}$	$\frac{\alpha + f_d\beta}{f - f_d}$
16	5·250	58·36	0·716	693·1	143·1
15·735	5·374	58	0·724	690·2	140·6
15	5·660	57	0·754	686·7	136·6
14·510	5·899	56	0·785	682·4	134·4
14·019	6·139	55	0·818	682·4	132·7
14	6·143	54·96	0·820	682·6	132·2
13·529	6·407	54	0·851	680·2	133·2
13·039	6·687	53	0·887	680·0	128·5
13	6·692	52·92	0·890	678·4	128·3
12·549	6·929	52	0·923	677·5	126·8
12·059	7·298	51	0·961	673·6	123·7
12	7·333	50·88	0·982	674·9	125·1
11·568	7·649	50	1·00	671·0	120·6
11·079	8·012	49	1·042	668·9	118·8
11	8·104	48·84	1·049	667·4	117·8
10·588	8·528	48	1·082	664·2	114·1
10·098	8·990	47	1·128	662·8	112·8
10	9·000	46·8	1·138	662·0	112·0
9·784	9·202	46	1·174	661·8	112·2
9·514	9·499	45	1·222	661·9	112·0
9·243	9·7960	44	1·273	662·5	112·1
9·0	10·111	43·1	1·320	661·8	111·6
8·970	10·149	43	1·326	660·7	111·4
8·676	10·502	42	1·380	661·6	111·2
8·382	10·903	41	1·439	660·8	110·5
8·088	11·397	40	1·500	658·8	109·1
8·0	11·500	39·7	1·519	659	109·2
7·942	11·599	39	1·569	661·4	111·6
7·500	12·303	38	1·630	660·0	108·3
7·206	12·898	37	1·703	660	106·4
7·0	13·186	36·3	1·752	655·6	105·7
6·919	13·497	36	1·778	652·6	104·8
6·648	14·003	35	1·857	654·0	104·3
6·378	14·700	34	1·940	654·6	103·7
6·108	15·396	33	2·033	653·3	102·7
6·0	15·790	32·6	2·069	652·6	101·6
5·85	16·099	32	2·105	650·4	100·88
5·60	16·709	31	2·226	651·6	102·60
5·35	17·699	30	2·333	650·0	99·90
5·1	18·200	29	2·449	653·9	100·50
5·0	19·200	28·6	2·499	647·7	97·70
4·8749	19·501	28	2·571	650·0	98·80
4·666	20·301	27	2·704	648·6	99·00
4·4583	21·401	26	2·847	647·0	97·96
4·25	22·481	25	3·000	647·9	97·80

Methyl alcohol in liquid. %	f	Methyl alcohol in vapour. %	f_d	$\frac{\alpha + f \cdot \beta}{f - f_d}$	$\frac{\alpha + f_d\beta}{f - f_d}$
4·0417	23·797	24	3·167	647·1	97·00
4·00	24·000	23·8	3·200	647·0	96·92
3·84	25·001	23	3·348	645·7	96·64
3·64	26·499	22	3·542	645·0	95·90
3·44	28·099	21	3·762	645·5	95·30
3·24	29·898	20	4·0	637·2	94·68
3·04	31·899	19	4·266	643·4	94·40
3·0	32·333	18·8	4·325	644·1	94·06
2·80	34·700	18	4·550	642·4	91·59
2·55	38·200	17	4·882	638·5	88·20
2·30	42·456	16	5·250	635·7	85·02
2·05	47·799	15	5·660	630·4	80·00
2·0	49	14·8	5·759	629·5	79·20
1·8924	51·895	14	6·143	629·2	79·20
1·7573	56·399	13	6·692	629·2	79·16
1·6222	60·698	12	7·333	630·7	80·36
1·4871	66·297	11	8·091	630·8	80·83
1·3520	73·080	10·0	9·0	631·4	81·29
1·2169	81·271	9·0	10·110	635·1	81·77
1·0818	91·492	8·0	11·500	632·1	82·25
1·0	99	7·40	12·501	632·3	82·40
0·9	114	6·68	13·998	632·0	82·50
0·8	124	5·96	15·802	631·5	83·54
0·7	141·9	5·24	18·099	630·7	82·45
0·6	165·7	4·52	21·103	630·5	81·70
0·5	199	3·80	25·319	630·8	81·53
0·4	249	3·00	32·333	632·2	83·125
0·3	332·33	2·20	44·46	635·5	85·65
0·2	499	1·40	70·40	640·3	90·85
0·1	999	0·60	165·67	659·0	108·50

TABLE 24 (CHART V)

Methyl Alcohol and Water

The reflux heat C_R required in *rectifying columns* to separate 1 kg. methyl alcohol as an 80, 90, 99% wt. product from aqueous mixtures containing from 94·16 to 0·08% wt.

The heat-expenditure C_a required in *boiling-columns* to separate 100 kg. spent wash from methyl alcohol and water mixtures of 71·11–0·08% (or, the heat required to raise the alcohol-content of such mixtures from 0·01% below to 90% above).

Initial content of methyl alcohol		Heat required to obtain 1 kg. methyl alcohol as a distillate of			
Liq. wt. %	Vap. wt. %	80% C_R kg. cal.	90% C_R kg. cal.	99% C_R kg. cal.	C_a kg. cal.
94·96	98	—	—	71·7	
85·58	95	—	—	127	
71·11	90	—	—	166	
57·06	85	—	76·9	196	106,500
44·78	80	—	132	228	61,270
34·70	75	69·0	185	270	39,820
26·71	70	132·2	241	318	28,180
21·20	65	208·5	309	383	21,160
17·21	60	291·2	389	459	17,320
14·02	55	386·2	487	549	15,000
11·57	50	503·2	575	673	13,270
9·51	45	643·4	734	802	12,060
8·09	40	820·5	915	982	11,198
6·65	35	1,051	1,142	1,208	10,980
5·35	30	1,354	1,444	1,510	10,430
4·25	25	1,782	1,872	1,937	9,990
3·64	22	2,122	2,195	2,277	9,780
3·25	20	2,411	2,489	2,566	9,590
2·55	17	2,956	3,025	3,108	9,468
2·05	15	3,443	3,529	3,596	8,820
1·62	12	4,517	4,658	4,613	8,000
1·35	10	5,521	5,609	5,676	8,036
1·22	9	6,262	6,385	6,420	8,129
1·08	8	7,110	7,190	7,268	8,177
0·95	7	8,190	8,275	8,347	8,225
0·89	6	9,928	9,931	9,935	8,000
0·67	5	11,879	12,036	12,190	.
0·53	4	15,000	15,114	15,150	.
0·40	3	20,275	20,363	20,426	.
0·28	2	31,000	31,000	31,017	8,300 ?
0·15	1	62,350	62,351	62,370	.
0·08	0·5	125,000	125,000	125,000	.
0·07	0·45	—	—	—	11,000 ?

For use with Chart V

TABLE 25 (CHART X)

Methyl Alcohol and Water

Methyl-alcohol content of liquid and vapour on each plate of *rectifying columns* when vapour containing 99% of methyl alcohol is produced with a reflux-heat expenditure C_R of from 3,000 to 250,000 kg. cal. for every 10 kg. of methyl alcohol recovered.

No. of plate from top.	Reflux heat C_R for 10 kg. Methyl Alcohol.													
	3,000 kg. cal.		5,000 kg. cal.		6,000 kg. cal.		8,000 kg. cal.		10,000 kg. cal.		20,000 kg. cal.		30,000 kg. cal.	
	L. %	V. %	L. %	V. %	L. %	V. %	L. %	V. %	L. %	V. %	L. %	V. %	L. %	V. %
	97·06	99·0	97·06	99·0	97·06	99·0	97·06	99·0	97·06	99·0	97·06	99·0	97·06	99·0
1	94·0	98·0	93·4	97·7	93·36	97·6	93·1	97·5	97·0	98·99	96·7	98·85	96·3	98·75
2	90·0	96·5	87·6	95·55	86·4	95·1	84·5	94·0	84·8	94·68	81·8	93·5	80·6	93·0
3	86·2	95·0	76·6	91·9	73·0	90·7	67·0	88·5	65·6	88·10	54·7	84·2	48·8	81·7
4	78·0	92·5	58·9	85·4	50·0	82·4	38·2	77·0	32·9	74·10	18·8	62·2	14·02	55·0
5	68·1	88·9	37·0	76·0	26·2	69·7	17·2	60·0	13·45	53·9	6·65	35·0	4·48	26·2
6	56·1	84·7	22·5	66·2	15·37	58·0	10·5	49·0	8·83	42·5	4·52	26·3	3·04	19·0
7	45·2	80·2	18·0	61·0	13·7	54·5	9·7	45·5	8·15	40·25	4·15	24·75	2·65	17·8
8	38·2	76·7	16·5	58·75	13·0	53·0	9·6	45·3	8·0	39·8	4·11	24·3	2·61	17·66
9	34·1	74·1	15·75	58·0	—	—	—	—	—	—	—	—	—	—
10	31·8	73·5	—	—	—	—	—	—	—	—	—	—	—	—
11	30·0	72·3	—	—	—	—	—	—	—	—	—	—	—	—

	40,000 kg. cal.		50,000 kg. cal.		100,000 kg. cal.		150,000 kg. cal.		200,000 kg. cal.		250,000 kg. cal.	
	97·06	99·0	97·06	99·0	97·06	99·0	97·06	99·0	97·06	99·0	97·06	99·0
1	96·0	98·64	92·8	97·42	91·9	97·15	91·45	97·1	91·4	97·11	91·38	97·04
2	78·8	92·5	78·2	92·42	76·8	91·9	76·5	91·8	76·0	91·7	75·66	91·6
3	45·7	80·3	44·0	79·60	39·33	77·44	38·1	76·85	37·3	76·45	36·5	76·1
4	11·8	50·5	10·1	48·90	8·45	41·25	8·09	40·0	7·9	38·9	7·45	37·8
5	3·64	22·0	3·11	19·30	1·80	13·24	1·49	11·1	1·41	10·44	1·26	9·3
6	2·07	15·1	3·68	12·5	0·91	6·92	0·66	5·05	0·58	4·35	0·45	3·4
7	1·87	13·8	1·53	11·3	0·81	6·10	0·575	4·30	0·40	3·0	0·35	2·61
8	1·84	13·6	—	—	—	—	—	—	—	—	—	—

Rectification up to 25% wt.

	5,000 kg. cal.		10,000 kg. cal.		20,000 kg. cal.		30,000 kg. cal.		40,000 kg. cal.		60,000 kg. cal.		80,000 kg. cal.	
1	4·35	25·0	4·25	25·0	4·25	25·0	4·25	25·0	4·25	25·0	4·25	25·0	4·25	25·0
2	3·44	21·0	2·95	18·4	2·05	15·0	1·75	12·9	1·55	11·5	1·0	8·1	0·95	7·0
3	3·44	21·0	2·70	17·75	1·80	13·9	1·55	11·5	1·30	8·75	—	—	0·30	5·96

	100,000 kg. cal.		150,000 kg. cal.		200,000 kg. cal.	
1	4·25	25·0	4·25	25·0	4·25	25·0
2	0·925	6·8	0·9	6·68	0·82	6·0
3	0·75	5·5	—	—	—	—

TABLE 26 (CHART XI)

Methyl Alcohol and Water

Highest alcohol-content (in wt. %) of the vapour from 0·5–15·0% mixtures of methyl alcohol and water when these enter continuous-distillation apparatus at 0°–90° C. Heat C_h required to raise the mixture to boiling-temperature, calculated for 10 kg. methyl alcohol. The weight of mixture required to yield 10 kg. methyl alcohol is given in parentheses in column 1.

Alcohol-content of mixture. wt. %		Difference in °C. between temp. at entry and boiling-temp.						
		0°	10°	20°	30°	50°	70°	90°
	C_h kg. cal.	0	20,000	40,000	60,000	100,000	140,000	180,000
0·5	in vapour %	3·8	4·2	5·0	6·25	9·95	17·0	28
(2000)	in liquid %	0·5	0·56	0·74	0·84	1·38	2·55	4·9
	C_h kg. cal.	0	10,000	20,000	30,000	50,000	70,000	90,000
1·0	in vapour %	7·4	8·4	9·8	11·75	15·5	22·0	35·7
(1000)	in liquid %	1·0	1·14	1·32	1·61	2·17	3·6	7·4
	C_h kg. cal.	0	6,667	13,333	20,000	33,333	46,666	60,000
1·5	in vapour %	11·1	12·5	14	15·5	19·8	27·8	40·5
(667)	in liquid %	1·5	1·68	1·89	2·3	3·1	4·8	8·2
	C_h kg. cal.	0	5,000	10,000	15,000	25,000	35,000	45,000
2·0	in vapour %	14·8	16·1	17·16	19·5	24·5	32·5	46
(500)	in liquid %	2·0	2·17	2·51	3·1	4·04	6·0	9·78
	C_h kg. cal.	0	3,333	6,667	10,000	16,667	23,333	30,000
3	in vapour %	18·8	20·6	22·66	24·25	32·0	40·2	50·0
(333)	in liquid %	3·0	3·4	3·75	4·3	5·85	8·08	11·586
	C_h kg. cal.	0	2,000	4,000	6,000	10,000	14,000	18,000
5	in vapour %	28·6	30·5	33·0	36·4	42·5	49·25	56·25
(200)	in liquid %	5·0	5·47	6·0	7·0	8·8	11·20	14·5
	C_h kg. cal.	0	1,433	2,866	4,300	7,166	10,033	12,900
7	in vapour %	36·3	39·4	42·0	45·0	50·8	56·33	60·5
(143)	in liquid %	7·0	8·0	8·64	9·51	12·0	14·66	17·5
	C_h kg. cal.	0	1,000	2,000	3,000	5,000	7,000	9,000
10	in vapour %	46·8	48·7	50·7	54	58	61·25	65·6
(100)	in liquid %	10	10·87	11·99	3·53	15·73	18·17	21·2
	C_h kg. cal.	0	715	1,431	2,146	3,557	5,007	6,438
15	in vapour %	57	58·6	60·25	62·5	65·5	68·3	70·2
(66)	in liquid %	15	16·27	16·66	19	21·1	24·3	27

TABLE 27 (CHART XII)

Methyl Alcohol and Water

Methyl-alcohol content of liquid and vapour on each plate of *boiling-columns* when the heat-expenditure C_a ranges from 13,000 to 100,000 kg. cal. per 100 kg. of exhausted liquor.

No. of plate from base.	Heat-expenditure C_a for 100 kg. spent liquor.									
	13,000 kg. cal.		14,000 kg. cal.		15,000 kg. cal.		17,000 kg. cal.		20,000 kg. cal.	
	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %
18	0·13	0·79	0·455	3·34	4·25	25	15·55	57·7	24·9	68·7
17	0·11	0·65	0·295	2·15	2·90	18·4	12·25	51·5	24·6	68·4
16	0·10	0·59	0·220	1·49	1·68	12·66	8·95	42·9	23·3	67·1
15	0·083	0·50	0·160	1·07	1·00	7·45	6·10	32·8	21	64·8
14	0·070	0·41	0·133	0·80	0·58	4·43	4·04	24·0	17·56	60·5
13	0·065	0·39	0·100	0·61	0·395	2·90	2·30	16·0	12·75	52·55
12	0·051	0·31	0·082	0·50	0·30	2·2	1·25	9·26	8·23	40·5
11	0·048	0·29	0·070	0·41	0·19	1·16	0·70	5·24	4·83	27·8
10	0·041	0·25	0·065	0·39	0·15	0·90	0·48	2·9	2·42	16·5
9	0·035	0·21	0·051	0·31	0·101	0·61	0·27	1·65	1·14	8·5
8	0·031	0·19	0·049	0·295	0·081	0·50	0·167	1·0	0·6	4·53
7	0·026	0·155	0·035	0·210	0·065	0·39	0·11	0·70	0·3	2·20
6	0·0233	0·140	0·031	0·19	0·05	0·30	0·081	0·49	0·18	1·075
5	0·021	0·125	0·029	0·175	0·035	0·21	0·051	0·31	0·10	0·60
4	0·017	0·101	0·025	0·150	0·029	0·175	0·0367	0·22	0·065	0·39
3	0·013	0·08	0·017	0·101	0·021	0·125	0·03	0·18	0·037	0·225
2	0·012	0·07	0·015	0·09	0·0165	0·100	0·018	0·11	0·025	0·15
1	0·010	0·061	0·0133	0·07	0·0133	0·08	0·015	0·09	0·015	0·09
0	0·01	0·06	0·01	0·06	0·01	0·06	0·01	0·06	0·01	0·06
	25,000 kg. cal.		30,000 kg. cal.		50,000 kg. cal.		70,000 kg. cal.		100,000 kg. cal.	
15	31	72·96	—	—	—	—	—	—	—	—
14	30·9	72·9	—	—	—	—	—	—	—	—
13	29·95	72·25	36	75·8	—	—	—	—	—	—
12	28·14	71·0	35	75·3	51·30	82·85	—	—	—	—
11	23·2	67·1	32·1	73·7	51·1	82·8	61·0	86·20	—	—
10	16·4	58·95	25·4	69·2	50·1	82·4	60·1	86·1	69	89·24
9	9·28	44·8	15·6	57·9	47·045	81·0	59·1	85·8	68·33	89·00
8	5·13	29·2	8·38	41·0	40·1	77·7	55·5	84·5	65·55	88·0
7	2·30	16·0	3·64	22·0	23·6	67·4	42·8	79·1	57·06	85·0
6	0·948	7·1	1·35	10·0	8·98	43·5	21·2	65·0	36·4	76·0
5	0·40	3·0	0·50	3·8	2·8	18·0	6·65	35·0	12·1	51·25
4	0·199	1·32	0·20	1·4	0·8	5·95	1·55	11·55	2·8	18·0
3	0·10	0·60	0·095	0·57	0·22	1·60	0·47	2·79	0·585	4·4
2	0·05	0·299	0·049	0·295	0·082	0·495	0·133	6·8	0·15	0·9
1	0·178	0·107	0·018	0·12	0·031	0·19	0·033	0·20	0·038	0·23
0	0·01	0·06	0·01	0·06	0·01	0·06	0·01	0·06	0·01	0·06

TABLE 28 (CHART II)

Methyl Alcohol and Water

A liquid mixture of methyl alcohol and water $a + w$ is vaporised in stages, each of the residual liquids $a_R + w_R$ being 1% weaker than the previous one. f_{dm} is the mean ratio of the vapours from $a + w$ and $a_R + w_R$.

$$a_d = \frac{a(f_R - f)}{f_R - f_{dm}} \qquad a_R = \frac{a(f - f_{dm})}{f_R - f_{dm}}.$$

Initial liquid contains	Resid. liquid contains	Mean ratio of vapours.	Alcohol in each residual liquid, if before vaporising $a = 1$.	Water in each residual liquid, if before vaporising $a = 1$.	Resid. liquid in each residual liquid, if before vaporising $a = 1$.	Residual liquid for series of 10 stages.		Residual liquid from 50% to end.
a %	a_R %	f_{dm}	a_R kg.	w_R kg.	$a_R + w_R$ kg.	$a_R + w_R$ kg.	$a_R + w_R$ %	$a_R + w_R$ %
50	49	0·2185	0·949	0·986	1·932	1·932	96·6	96·6
49	48	0·2245	0·949	1·024	1·973	1·773	88·7	88·7
48	47	0·2335	0·949	1·072	2·021	1·725	86·25	86·25
47	46	0·2410	0·949	1·110	2·059	1·668	83·4	83·4
46	45	0·2460	0·949	1·157	2·106	1·490	74·5	74·5
45	44	0·2530	0·949	1·205	2·154	1·440	72·0	72·0
44	43	0·2595	0·948	1·257	2·205	1·400	70·0	70·0
43	42	0·2660	0·948	1·308	2·256	1·354	67·7	67·7
42	41	0·2740	0·947	1·362	2·309	1·316	65·8	65·8
41	40	0·2820	0·947	1·420	2·367	1·278	63·9	63·9
40	39	0·2860	0·947	1·480	2·427	2·427	97·08	62·0
39	38	0·2995	0·947	1·543	2·490	2·233	89·32	60·6
38	37	0·3075	0·946	1·608	2·554	2·162	86·48	58·3
37	36	0·3155	0·946	1·680	2·626	2·110	89·40	55·5
36	35	0·3255	0·946	1·755	2·701	2·054	82·16(I)	54·0
35	34	0·3305	0·946	1·835	2·781	2·001	80·04	52·5
34	33	0·3460	0·945	1·918	2·863	1·944	77·76	51·05
33	32	1·3528	0·945	1·984	2·929	1·881	75·24	49·4
32	31	0·3654	0·945	2·100	3·045	1·845	73·80	48·5
31	30	0·3771	0·944	2·201	3·145	1·805	72·20	47·5
30	29	0·3898	0·943	2·305	3·248	3·248	97·44	45·5
29	28	0·4038	0·949	2·420	3·362	2·983	89·49	44·7
28	27	0·4165	0·941	2·540	3·481	2·909	87·27	43·75
27	26	0·421	0·939	2·676	3·615	2·833	84·99(II)	42·5
26	25	0·446	0·939	2·817	3·756	2·760	82·80	41·4
25	24	0·463	0·939	2·972	3·911	2·697	80·91	40·3
24	23	0·486	0·937	3·133	4·070	2·629	78·87	39·45
23	22	0·509	0·935	3·309	4·244	2·562	76·86	38·3
22	21	0·521	0·932	3·504	4·426	2·488	76·64	37·15
21	20	0·555	0·930	3·720	4·650	2·425	72·75	36·25

Initial liquid contains	Resid. liquid contains	Mean ratio of vapours.	Alcohol in each residual liquid, if before vaporising $a = 1$.	Water in each residual liquid, if before vaporising $a = 1$.	Resid. liquid in each residual liquid, if before vaporising $a = 1$.	Residual liquid for series of 10 stages.		Resid. liquid from 50% to end.
a %	a_R %	f_{dm}	a_R kg.	w_R kg.	a_R+w_R kg.	$a_R + w_R$ kg.	%	a_R+w_R %
20	19	0·584	0·928	3·958	4·886	4·886	97·7	35·2
19	18	0·619	0·924	4·204	5·128	4·390	87·8	34·1
18	17	0·657	0·921	4·494	5·415	4·270	85·4	33·0
17	16	0·696	0·918	4·819	5·737	4·154	83·1(III)	32·05
16	15	0·735	0·915	5·178	6·093	4·037	80·7	31·05
15	14	0·787	0·909	5·582	6·491	3·906	78·1	30·08
14	13	0·855	0·904	6·047	6·961	3·786	75·7	29·16
13	12	0·935	0·900	6·597	7·497	3·667	73·4	28·28
12	11	1·015	0·896	7·248	8·141	3·565	71·3	27·51
11	10	1·110	0·890	8·010	8·900	3·471	69·4	26·74
10	9	1·229	0·876	8·760	9·636	9·636	96·36	25·28
9	8	1·419	0·862	9·910	10·772	8·10	81·0	24·3
8	7	1·635	0·847	11·110	11·957	7·62	76·2	22·70
7	6	1·910	0·812	12·820	13·632	7·05(IV)	70·5	20·55
6	5	2·284	0·798	15·320	16·118	6·66	66·6	19·80
5	4	2·849	0·774	18·570	19·344	6·15	61·5	18·40
4	3	3·763	0·708	22·800	23·508	5·21	53·1	16·05
3	2	5·042	0·612	29·980	30·592	4·22	42	12·85
2	1	9·130	0·444	43·950	44·394	2·732	27·32	8·39

TABLE 29 (CHART II). Methyl Alcohol and Water

A vapour mixture of methyl alcohol and water $a_s + w_s =$ 1·666 kg., in which $a_s = 1$, is condensed in stages so that each residual vapour $a_e + w_e$ is 1% richer than the previous one. f_{Rm} is the mean ratio of the liquids from which $a_s + w_s$ and $a_e + w_e$ were produced. $a_e = \frac{a_s(f_{Rm} - f_s)}{f_{Rm} - f_e}$.

Initial vapour contains	Resid. vapour contains	Mean ratio of liquid.	Alcohol in resid. vapour at each stage, if before vaporising $a_s = 1$	Water in resid. vapour at each stage, if before vaporising $a_s = 1$	Resid. vapour of each stage. $a_e + w_e$		Resid. vapour after n condensations. $a_n + w_n$	
a_s %	a_e %	f_{Rm}	a_e kg.	w_e kg.	kg.	%	kg.	%
60	61	4·699	0·993	0·6345	1·627	97·6	1·628	97·6
61	62	4·473	0·993	0·6087	1·602	96·0	1·590	95·4
62	63	4·263	0·993	0·5828	1·576	94·5	1·554	93·4
63	64	4·058	0·992	0·5584	1·550	93·0	1·518	91·0
64	65	3·834	0·992	0·5336	1·526	91·5	1·481	88·8
65	66	3·640	0·992	0·5108	1·503	90·0	1·447	86·8
66	67	3·406	0·991	0·4845	1·476	88·5	1·409	84·2
67	68	3·221	0·991	0·4657	1·456	87·3	1·377	82·6
68	69	3·096	0·991	0·4449	1·436	86·1	1·348	80·8
69	70	2·854	0·991	0·4251	1·416	84·8	1·318	79·0
70	71	2·649	0·990	0·4049	1·395	83·7	1·286	77·1
71	72	2·468	0·990	0·3851	1·375	82·5	1·256	75·3
72	73	2·298	0·990	0·3659	1·355	81·2	1·225	73·5
73	74	2·124	0·989	0·3481	1·337	80·2	1·195	71·7
74	75	1·963	0·988	0·3290	1·317	79·6	1·164	69·7
75	76	1·818	0·988	0·3122	1·300	78·0	1·136	68·1
76	77	1·675	0·988	0·2954	1·283	76·9	1·108	66·5
77	78	1·539	0·987	0·2783	1·265	75·9	1·079	64·7
78	79	1·413	0·986	0·2622	1·248	74·8	1·051	63·0
79	80	1·292	0·985	0·2462	1·231	73·8	1·023	61·3
80	81	1·182	0·981	0·2295	1·210	72·6	0·987	59·4
81	82	1·078	0·980	0·2146	1·194	71·5	0·953	57·5
82	83	0·979	0·980	0·2009	1·181	70·8	0·906	54·4
83	84	0·887	0·979	0·1869	1·166	70·0	0·872	52·3
84	85	0·797	0·975	0·1716	1·147	68·8	0·842	50·5
85	86	0·708	0·973	0·1576	1·131	67·8	0·806	48·4
86	87	0·629	0·971	0·1446	1·116	66·9	0·770	46·2
87	88	0·560	0·965	0·1312	1·096	65·8	0·737	44·2
88	89	0·495	0·963	0·1184	1·081	64·8	0·697	41·8
89	90	0·435	0·960	0·1065	1·066	64·0	0·660	39·6
90	91	0·385	0·956	0·0946	1·051	63·0	0·622	37·3
91	92	0·332	0·950	0·0826	1·033	61·9	0·580	34·8
92	93	0·275	0·940	0·0707	1·011	60·6	0·534	32·0
93	94	0·229	0·927	0·0591	0·986	59·2	0·483	28·9
94	95	0·189	0·918	0·0482	0·966	58·0	0·419	25·1
95	96	0·149	0·896	0·0374	0·933	56·0	0·375	22·5
96	97	0·112	0·875	0·0270	0·902	54·1	0·308	18·5
97	98	0·074	0·817	0·0167	0·834	49·9	0·240	14·4
98	99	0·047	0·721	0·0072	0·728	43·7	0·151	9·06
99	100	0·020	0·666	0·0033	0·669	40·1	0·093	5·58

TABLE 30 (CHART III)

$\alpha = 125{\cdot}28$
$\beta = 537{\cdot}00$

Acetone and Water

Acetone-content of liquid acetone-water mixtures and of the vapours therefrom. Ratios of the liquids $\frac{w}{a} = f$ and of the vapours $\frac{w_d}{a_d} = f_d$. Values of $\frac{\alpha + f\beta}{f - f_d}$ and $\frac{\alpha + f_d\beta}{f - f_d}$.

The percentage figures are those of H. Bergström, amplified by the author. Temperatures in brackets [ ] are due to H. R. Carveth (*J. Phys. Chem.*, 1899, 3, 193), and those in parentheses ( ) to J. H. Pettit (*ibid.*, 1899, 3, 349).

Boil.-temp. of liquid in °C.	Acetone in liquid wt. %	f	Acetone in vapour wt. %	f_d	$\frac{\alpha + f\beta}{f - f_d}$	$\frac{\alpha + f_d\beta}{f - f_d}$
(56·9)	100	0	100	0	∞	∞
[56·15]	99·5	0·005025	99·75	0·00251	50,955	50,437
	99	0·0101	99·50	0·005025	25,611	24,940
	98·5	0·0152	99·25	0·0076	17,300	16,820
	98	0·0204	99·0	0·0101	13,214	12,689
	97·5	0·0257	98·75	0·0127	10,691	10,168
	97	0·0309	98·50	0·01529	9,057	8,557
	96·5	0·0363	98·25	0·0178	7,745	7,286
	96	0·0417	98·0	0·0204	6,962	6,425
	95·5	0·0471	97·75	0·0230	6,240	5,714
[57·2]	95	0·0525	97·5	0·0257	5,723	5,190
	94·5	0·0582	97·38	0·026866	4,995	4,462
	94	0·0638	97·26	0·028032	4,455	3,918
	93·5	0·0695	97·14	0·029198	4,032	3,494
	93	0·0752	97·02	0·030364	3,688	3,153
	92·5	0·0811	96·90	0·031530	3,413	2,872
	92	0·0869	96·78	0·032696	3,172	2,635
	91·5	0·0929	96·66	0·033862	2,963	2,429
	91	0·0990	96·54	0·035028	2,790	2,252
	90·5	0·1050	96·42	0·036194	2,640	2,104
—	90	0·1110	96·3	0·037360	2,524	1,973
	89·5	0·1173	96·24	0·038526	2,387	1,845
[58·3]	89	0·1230	96·18	0·03969	2,295	1,759
(59)	88·5	0·1299	96·02	0·04035	2,175	1,640
	88	0·1360	96·06	0·04102	2,088	1,551
	87·5	0·1427	96·00	0·04168	1,998	1,461
	87	0·1490	95·94	0·042229	1,930	1,389
	86·5	0·1558	95·88	0·042778	1,846	1,310
	86	0·1600	95·82	0·043327	1,812	1,274
[58·9]	85·5	0·1695	95·76	0·043876	1,730	1,190

Boil.-temp. of liquid in °C.	Acetone in liquid wt. %	f	Acetone in vapour wt. %	f_d	$\frac{\alpha + f\beta}{f - f_d}$	$\frac{\alpha + f_d\beta}{f - f_d}$
—	85	0·1760	95·7	0·044425	1677	1137
	84·5	0·1833	95·66	0·044974	1619	1082
	84	0·190	95·62	0·0455	1577·7	1040
	83·5	0·198	95·58	0·0461	1529	994
	83	0·205	95·54	0·0466	1489	949
	82·5	0·212	95·50	0·0471	1448	943
	82	0·219	95·46	0·0476	1420	882
	81·5	0·227	95·42	0·0480	1382	846
	81	0·234	95·38	0·0485	1354	817
	80·5	0·242	95·34	0·0489	1323	786
—	80	0·250	95·30	0·0494	1297	759
	79·5	0·258	95·26	0·0498	1265	733
	79	0·266	95·22	0·0502	1243	705
	78·5	0·274	95·18	0·0507	1222	683
[59·7]	78	0·282	95·14	0·0511	1200	662
	77·5	0·290	95·10	0·0516	1180	642
	77	0·2987	95·06	0·0520	1161	622
(60·7)	76·5	0·307	95·02	0·0525	1141	603
	76	0·316	94·98	0·0528	1100	583
	75·5	0·324	94·94	0·0532	1104	567
—	75	0·333	94·90	0·0535	1088	550
	74·5	0·342	94·87	0·0539	1073	538
	74	0·352	94·84	0·0542	1055	517
	73·5	0·360	94·81	0·0546	1046	506
	73	0·370	94·78	0·0549	1028	491
	72·5	0·379	94·75	0·0553	1016	478
[60·45]	72	0·389	94·72	0·0557	1003	465
	71·5	0·397	94·69	0·0560	993	456
	71	0·409	94·66	0·0564	979	441
	70·5	0·418	94·63	0·0567	970	431
—	70	0·429	94·6	0·0571	957	417
	69·5	0·439	94·57	0·0574	947	410
	69	0·449	94·54	0·0578	939	399
	68·5	0·460	94·51	0·0582	927	390
	68	0·472	94·48	0·0585	916	379
	67·5	0·481	94·45	0·0588	910	371
	67	0·493	94·42	0·0591	895	362
	66·5	0·503	94·39	0·0595	892	355
[61·0]	66	0·515	94·36	0·0598	883	345
(61·6)	65·5	0·526	94·33	0·0601	877	339
—	65	0·538	94·30	0·0605	868	331
	64·5	0·550	94·27	0·0608	860	323
	64	0·563	94·24	0·0611	852	315
	63·5	0·573	94·21	0·0614	846	309
	63	0·587	94·18	0·0618	838	300
	62·5	0·600	94·15	0·0621	832	295

Boil.-temp. of liquid in °C.	Acetone in liquid wt. %	f	Acetone in vapour wt. %	f_d	$\frac{\alpha + f\beta}{f - f_d}$	$\frac{\alpha + f_d\beta}{f - f_d}$
	62	0·613	94·12	0·0624	825	289
	61·5	0·626	94·09	0·0628	819	282
	61	0·639	94·06	0·0631	814	276
(62·4)	60·5	0·652	94·03	0·0634	807	271
—	60	0·666	94·00	0·0638	800	266
	59·5	0·680	93·96	0·0642	797	259
	59	0·695	93·92	0·0646	791	254
	58·5	0·709	93·88	0·0651	785	249
	58	0·724	93·84	0·0655	780	244
	57·5	0·739	93·80	0·0660	775	238
	57	0·754	93·76	0·0664	770	234
	56·5	0·770	93·72	0·0668	766	229
	56	0·785	93·68	0·0673	762	225
	55·5	0·801	93·64	0·0677	757	223
—	55	0·818	93·60	0·0683	753	216
[62]	54·5	0·834	93·57	0·0686	749	212
(63)	54	0·851	93·54	0·0691	744	207
	53·5	0·869	93·51	0·0695	740	204
	53	0·887	93·48	0·0699	736	199
	52·5	0·904	93·45	0·0702	732	195
	52	0·923	93·42	0·0705	728	191
	51·5	0·941	93·39	0·0708	724·6	187·6
	51	0·964	93·36	0·0709	721·1	183·5
	50·5	0·980	93·33	0·0712	717·2	179·9
—	50	1·00	93·30	0·0713	714·4	176·1
	49·5	1·020	93·27	0·0714	709	172·4
	49	1·042	93·24	0·0715	705	168·5
	48·5	1·062	93·21	0·0716	702·4	165
	48	1·082	93·18	0·0717	699	162
	47·5	1·105	93·15	0·0718	697	158
[63·23]	47	1·128	93·12	0·0719	694·5	155
(64·2)	46·5	1·1503	93·09	0·0721	691	152
	46	1·174	93·06	0·0722	687	149
(64·4)	45·5	1·198	93·03	0·0720	684	146
—	45	1·222	93·00	0·0723	683	143
	44·5	1·247	92·95	0·0734	679	141
	44	1·273	92·90	0·0743	678	138
	43·5	1·299	92·85	0·0751	674	136
	43	1·326	92·80	0·0769	671	133
	42·5	1·353	92·75	0·0768	669	130
	42	1·381	92·70	0·0776	667	128
	41·5	1·419	92·65	0·0786	664	126
	41	1·439	92·60	0·0794	662	124
(65·3)	40·5	1·469	92·55	0·0803	659	121
—	40	1·500	92·50	0·0811	657	119
	39·5	1·531	92·43	0·0821	653	117

Boil.-temp. of liquid in °C.	Acetone in liquid wt. %	f	Acetone in vapour wt. %	f_d	$\frac{\alpha + f\beta}{f - f_d}$	$\frac{\alpha + f_d\beta}{f - f_d}$
	39	1·564	92·36	0·0830	651	115
	38·5	1·597	92·29	0·0839	650	113
	38	1·632	92·22	0·0849	649	111
	37·5	1·666	92·15	0·0858	644	108
	37	1·703	92·08	0·0867	643	106
	36·5	1·739	92·01	0·0876	642	104
[65·9]	36	1·778	91·94	0·0885	640	102
	35·5	1·817	91·87	0·0895	638·6	100·6
—	35	1·857	91·8	0·0904	636·5	98·5
	34·5	1·899	91·72	0·0914	634·3	96·6
	34	1·941	91·64	0·0923	632·8	94·7
(67)	33·5	1·985	91·56	0·0933	630·0	92·7
	33	2·033	91·48	0·0942	629·1	90·8
	32·5	2·077	91·40	0·0952	626·5	89·1
	32	2·124	91·32	0·0961	625·3	87
	31·5	2·174	91·24	0·0971	623·0	85·5
	31	2·225	91·16	0·0980	620·4	83·6
	30·5	2·278	91·08	0·0989	620·3	82·1
—	30	2·333	91·00	0·0990	616·8	80·1
	29·5	2·389	90·88	0·1004	616·2	78·5
	29	2·449	90·76	0·1019	614·8	76·8
	28·5	2·508	90·64	0·1033	612·3	75·2
	28	2·571	90·52	0·1048	611·4	73·6
	27·5	2·636	90·40	0·1062	610·2	72·2
	27	2·704	90·28	0·1077	608·7	70·6
	26·5	2·773	90·16	0·1092	605·2	68·9
	26	2·847	90·04	0·1106	604·5	67·6
	25·5	2·941	89·92	0·1121	603·2	65·6
—	25	3·00	89·8	0·1136	602·3	64·6
[70·7]	24·5	3·081	89·59	0·1162	599·5	63·2
	24	3·167	89·38	0·1188	598·9	62·0
[78·95]	23·5	3·255	89·17	0·1215	597·4	60·8
	23	3·348	88·96	0·1241	596·7	59·5
	22·5	3·454	88·75	0·1268	596·1	58·6
	22	3·542	88·52	0·1296	594·1	57·1
	21·5	3·651	88·29	0·1331	592·1	55·7
	21	3·762	88·06	0·1356	591·6	54·8
	20·5	3·878	87·83	0·1386	591·4	53·5
—	20	4·00	87·6	0·1415	588	52·0
	19·5	4·128	87·28	0·1458	587	50·9
[71·9]	19	4·266	86·96	0·1499	586	49·9
74·3	18·5	4·405	86·64	0·1542	585	48·8
	18	4·550	86·32	0·1584	583	47·7
[73·3]	17·5	4·714	86	0·1600	582	46·2
	17	4·882	85·64	0·1677	581	45·5
[73·56]	16·5	5·060	85·28	0·1726	580	44·3

Boil.-temp. of liquid in °C.	Acetone in liquid wt. %	f	Acetone in vapour wt. %	f_d	$\frac{\alpha + f\beta}{f - f_d}$	$\frac{\alpha + f_d\beta}{f - f_d}$
	16	5·250	84·92	0·1775	579	43·7
	15·5	5·451	84·56	0·1826	578	42·3
—	15	5·660	84·2	0·1875	577	41·0
	14·5	5·896	83·78	0·1936	576	40·0
	14	6·143	83·37	0·1996	574	38·9
	13·5	6·407	82·95	0·2054	573	37·8
	13	6·692	82·47	0·2127	572	36·8
[77·16]	12·5	7·00	81·93	0·2198	571	35·7
	12	7·333	81·5	0·2269	570	34·5
	11·5	7·695	80·73	0·2388	569	33·9
(81·1)	11	8·104	79·95	0·2508	568	33·0
	10·5	8·526	79·18	0·2630	568	32·1
—	10	9	78·4	0·2754	567	31·1
[80·7]	9·5	9·520	77·6	0·2885	567	30·2
	9	10·111	76·8	0·3020	566	29·2
	8·5	10·800	75·6	0·3226	566	28·3
	8	11·5	74·4	0·3440	565	27·9
	7·5	12·330	72·8	0·3735	565	27·3
	7	13·286	71·2	0·4044	564	26·6
	6·5	14·380	69·3	0·4415	564	25·7
	6	15·79	67·4	0·4835	563	25·0
	5·5	17·180	65·1	0·5360	562	24·7
	5	19·2	62·6	0·5973	561	23·6
[88·7]	4·5	21·21	59·3	0·6862	560	23·57
	4	24	56·0	0·785	560	23·55
	3·5	27·51	51·70	0·934	560	23·53
	3	32·33	47·0	1·128	560	23·39
	2·5	39·0	41·6	1·404	560	23·24
[94·63]	2	49	36·0	1·778	560	23·0
	1·5	65·66	28·2	2·546	560	23·0
	1	99	20·4	3·911	560	23·0
	0·5	199	11·0	8·104	560	23·0
	0·4	249	8·93	10·200	560	23·0
	0·3	332·3	6·85	13·601	559	22·8
	0·2	499·0	4·78	19·950	558	22·4
99·8	0·1	999	2·7	36·030	558	20·2

TABLE 31 (CHART XIV)

Acetone and Water

Reflux heat C_R required in *rectifying columns* to produce 1 kg. acetone as 95–99·75% vapour from acetone-water mixtures of 95·5–1%.

Acetone-content of		Heat needed to obtain 1 kg. acetone as		Acetone content of		Heat needed to obtain 1 kg. acetone as	
Liq. wt. %	Vap. wt. %	95% C_R kg. cal.	99·75% C_R kg. cal.	Liq. wt. %	Vap. wt. %	95% C_R kg. cal.	99·75% C_R kg. cal.
95·5	97·75	—	—	35	91·8	24·12	55·9
95	97·5	—	132·9	30	91·0	28·66	59·5
90	96·3	—	87·7	25	89·0	36·75	66·8
85	95·7	—	70·2	20	87·6	52·30	81·7
80	95·3	—	60·5	15	84·2	77·70	108·0
75	94·9	1·09	55·4	10	78·4	126·20	154·0
70	94·6	4·40	52·3	9	76·8	146·20	168·9
65	94·3	6·94	50·3	8	74·4	164·60	192·4
60	94	9·04	49·8	7	71·2	198·20	225·1
55	93·6	11·89	49·6	6	67·4	242·60	269·3
50	93·3	13·79	49·6	5	62·6	305·40	332·6
45	93·0	15·57	49·7	2	36·0	965·00	994·3
40	92·5	18·75	51·7	1	20·0	2160·00	2188·8

The heat of vaporisation C_a required in *boiling-columns* to separate 100 kg. water from 95·5–1% acetone-water mixtures (or, the heat required, per 100 kg. spent liquor, to raise the acetone-content of the vapour from 0·1% below to 97·75% above).

Acetone-content of liquid wt. %	Heat for 100 kg. spent liquor C_a	Acetone-content of liquid wt. %	Heat for 100 kg. spent liquor C_a	Acetone-content of liquid wt. %	Heat for 100 kg. spent liquor C_a
95·5	5,043,700	55	21,600	10	3,110
95	519,000	50	17,600	9	2,920
90	197,300	45	14,300	8	2,790
85	113,700	40	11,900	7	2,660
80	75,900	35	9,850	6	2,500
75	55,000	30	8,010	5	2,360
70	41,700	25	6,460	2	2,350
65	33,100	20	5,200	1	2,300
60	26,600	15	4,100		

TABLE 32 (CHART XIV)

Acetone and Water

Acetone-content of liquid and vapour on each plate of *rectifying columns* in the production of vapour containing 99·75% acetone (0·25% water), when the reflux-heat expenditure C_R ranges from 1,500 to 20,000 kg. cal. per 10 kg. acetone recovered.

No. of plate from base.	Reflux heat C_R for 10 kg. acetone.							
	1500 kg. cal.		2000 kg. cal.		2500 kg. cal.		3000 kg. cal.	
	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %
	99·5	99·75	99·5	99·75	99·5	99·75	99·5	99·75
1	99·0	99·5	99·2	99·6	99·19	99·55	99·0	99·5
2	98·75	99·4	98·82	99·43	98·75	99·35	98·6	99·3
3	98·6	99·3	98·4	99·2	98·2	99·06	97·9	98·98
4	98·27	99·11	98·0	98·97	96·85	98·4	96·9	98·48
5	97·9	98·98	97·75	98·7	95·75	97·9	95·75	97·87
6	97·0	98·5	96·8	98·4	94·0	97·2	93·1	97·06
7	96·1	98·13	96·0	98·0	89·0	96·2	83·0	95·53
8	95·6	97·78	95·25	97·6	82·0	95·50	24·6	89·63
9	95·2	97·6	93·5	97·14	25·5	89·92	18·3	86·56
10	94·2	97·3	91·6	96·7	7·6	72·9	6·1	67·81
11	93·0	97·0	82·0	95·46	6·5	69·3	5·5	65·13
12	92·1	96·89	29·5	90·88	6·35	68·8	—	—
13	88·25	96·09	9·09	76·50	—	—	—	—
14	69·1	94·56	8·0	74·8	—	—	—	—
15	22·0	88·48	7·88	73·9	—	—	—	—
16	11·0	80·1	7·77	73·8	—	—	—	—
17	10·75	79·5	—	—	—	—	—	—
18	10·4	78·95	—	—	—	—	—	—

	5,000 kg. cal.		10,000 kg. cal.		20,000 kg. cal.	
	99·5	99·75	99·5	99·75	99·5	99·75
1	99·0	99·5	98·9	99·47	98·9	99·4
2	98·5	99·25	98·0	99·0	97·8	98·9
3	96·6	98·3	96·5	98·2	96·2	98·1
4	94·5	97·39	92·8	96·99	87·1	95·98
5	86·5	95·83	58·0	93·84	22·0	88·51
6	26·0	90·03	7·0	71·6	2·0	36·32
7	4·66	60·46	4·8	61·25	1·15	22·45
8	3·7	53·07	2·4	40·0	—	—
9	3·6	52·5	2·0	36·0	—	—

TABLE 33 (Chart XIV)

Acetone and Water

$\alpha = 125{\cdot}25$
$\beta = 537$

Acetone-content of liquid and vapour on each plate in *boiling-columns* when the heat-expenditure C_a ranges from 2,500 to 12,000 kg. cal. per 100 kg. exhausted liquor.

No. of plate from base.	Heat-expenditure for 100 kg. water.									
	2,500 kg. cal.		3,000 kg. cal.		5,000 kg. cal.		8,000 kg. cal.		12,000 kg. cal.	
	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %
28	—	—	9·0	76·8	—	—	—	—	—	—
27	—	—	8·46	75·3	—	—	—	—	—	—
26	—	—	7·65	73·0	—	—	—	—	—	—
25	—	—	6·81	70·4	—	—	—	—	—	—
24	—	—	5·76	66·3	—	—	—	—	—	—
23	—	—	4·4	58·6	—	—	—	—	—	—
22	—	—	3·565	51·7	—	—	—	—	—	—
21	—	—	2·78	44·2	—	—	—	—	—	—
20	0·197	4·60	2·14	38·0	—	—	—	—	—	—
19	0·191	4·25	1·724	31·1	—	—	—	—	—	—
18	0·1518	3·73	1·3	26·0	—	—	—	—	—	—
17	0·1338	3·33	1·023	20·8	—	—	—	—	—	—
16	0·1130	2·93	0·825	16·9	—	—	—	—	—	—
15	0·0956	2·58	0·71	14·0	—	—	—	—	—	—
14	0·07697	2·077	0·5601	12·32	—	—	—	—	—	—
13	0·06360	1·717	0·4719	9·84	—	—	—	—	—	—
12	0·052445	1·416	0·3738	7·9	17·5	86·0	—	—	—	—
11	0·04235	1·144	0·27785	6·349	14·99	84·3	—	—	—	—
10	0·03468	0·9363	0·2187	5·0	10·05	78·7	—	—	—	—
9	0·02865	0·7735	0·1588	3·97	5·30	64·5	29·37	90·8	—	—
8	0·02375	0·64125	0·1129	2·934	2·6	43·45	27·25	90·3	—	—
7	0·019338	0·5221	0·0746	2·062	4·35	25·0	19·237	87·0	—	—
6	0·01601	0·4320	0·05278	1·425	0·6	14·0	8·0488	74·5	39·0	92·3
5	0·01317	0·3556	0·03692	0·9971	0·3	6·8	2·491	41·45	10·0	78·4
4	0·01080	0·2916	0·02614	0·7057	0·12	3·3	0·7887	16·72	2·5	41·6
3	0·00895	0·2417	0·01821	0·4916	0·05	1·5	0·249	5·801	0·607	12·8
2	0·00767	0·2008	0·01270	0·3429	0·027	0·63	0·062	1·884	0·115	3·1
1	0·006086	0·164	0·00716	0·1934	0·01	0·3	0·01756	0·4737	0·0246	0·664
	0·005	0·135	0·005	0·135	0·005	0·135	0·005	0·135	0·005	0·135
	15,000 kg. cal.		20,000 kg. cal.		25,000 kg. cal.		35,000 kg. cal.		55,000 kg. cal.	
7	45·7	93·0	53·0	93·48	—	—	—	—	—	—
6	41·6	92·7	52·25	93·43	58·0	93·8	66·1	94·36	75·0	94·9
5	23·0	88·8	41·5	92·64	50·25	93·3	62·25	94·1	73·5	94·81
4	5·1	63·5	12·7	82·1	18·75	86·45	32·0	91·32	56·0	93·68
3	1·05	20·4	1·9	37·1	2·78	44·05	4·4	59·1	9·8	78·0
2	0·19	4·5	0·27	6·7	0·37	8·30	0·55	11·5	0·85	18·0
1	0·03	0·8	0·037	1·0	0·043	1·15	0·0400	1·30	0·063	1·70
	0·005	0·135	0·005	0·135	0·005	0·135	0·005	0·135	0·005	0·135

TABLE 34 (CHART XV)

$\alpha = 125{\cdot}28$

Acetone and Methyl Alcohol $\beta = 265$

Acetone-content of liquid mixtures of acetone and methyl alcohol and of vapours arising therefrom. Ratios of liquids $\frac{m}{a} = f$ and of vapours $\frac{m_d}{a_d} = f_d$. Values of $\frac{\alpha + f\beta}{f - f_d}$ and $\frac{\alpha + f_d\beta}{f - f_d}$.

According to J. H. Pettit (*J. Phys. Chem.*, 1899, 3, 349).

(Extended by the author.)

Columns 4 and 8 contain Bergström's values for the acetone-content of vapours.

Boil.-temp. °C.	Acetone-content of Liq. wt. %	Vap. (Pettit) wt. %	Vap. (Bergström) wt. %	Boil.-temp. °C.	Acetone-content of Liq. wt. %	Vap. (Pettit) wt. %	Vap. (Bergström) wt. %
(56·7)	100	0		55·95	85·5	88·28	
	99·5	99·88			85	88	85·8
	99	99·75			84·5	87·75	
	98·5	99·63			84	87·5	85
	98	99·5		55·9	83·5	87·25	
	97·5	99·12			83	87	84·3
(56·4)	97	98·75			82·5	86·75	
	96·5	98·25			82	86·5	83·6
	96	97·75			81·5	86·25	
	95·5	97·25			81	86	82·8
	95	96·75			80·5	85·7	
	94·5	96·38			80	85·4	82·1
	94	96			79·5	85·1	
	93·5	95·5			79	84·8	81·5
(56·1)	93	95			78·5	84·5	
	92·5	94·5			78	84·28	80·8
	92	94·1	92		77·5	83·9	
	91·5	93·7			77	83·68	80·2
	91	93·2	91		76·5	83·4	
	90·5	92·65		56·1	76	83·18	79·6
	90	92·1	90		75·5	82·96	
	89·5	91·55			75	82·74	79
	89	91	89·1		74·5	82·54	
55·9	88·5	90·5			74	82·32	78·3
	88	90	88·2		73·5	82·10	
	87·5	89·5			73	81·88	77·7
	87	89	87·4		72·5	81·66	
	86·5	88·75			72	81·44	77
	86	88·5	86·6		71·5	81·22	

Boil.-temp. °C.	Acetone-content of Liq. wt. %	Vap. (Pettit) wt. %	Vap. (Bergström) wt. %	Boil.-temp. °C.	Acetone-content of Liq. wt. %	Vap. (Pettit) wt. %	Vap. (Bergström) wt. %
	71	81	76·4		67·5	79·1	
	70·5	80·75			67	78·8	73·9
	70	80·5	75·8		66·5	78·5	
	69·5	80·25		56·65	66	78·2	73·2
	69	80	75·1		65·5	77·9	
	68·5	79·7			65	77·6	72·6
	68	79·4	74·5		64·5	77·3	

Boil.-temp. °C.	Acetone in liquid a wt. %	f	Acetone in vapour a_d wt. %	f_a	$\frac{a+f\beta}{f-f_a}$	$\frac{a+f_a\beta}{f-f_a}$	Bergström a_d wt. %
	64	0·563	77	0·298	1035	771	71·9
	63·5	0·573	76·75	0·303	1024	758	
	63	0·587	76·5	0·307	1002	733	71·2
	62·5	0·600	76·2	0·312	985	721	
	62	0·613	75·9	0·318	972	706	70·6
	61·5	0·626	75·6	0·323	960	693	
	61	0·639	75·3	0·328	945	681	69·9
	60·5	0·652	75	0·333	932	666	
	60	0·666	74·7	0·339	921	657	69·2
	59·5	0·680	74·4	0·344	908	643	
	59	0·695	74·1	0·350	893	630	68·6
	58·5	0·709	73·8	0·355	882	617	
	58	0·724	73·5	0·361	871	607	67·9
	57·5	0·739	73·2	0·366	860	594	
57·5	57	0·754	72·9	0·372	850	586	67·3
	56·5	0·770	72·55	0·378	838	573	
	56	0·785	72·2	0·385	832	567	66·6
	55·5	0·801	71·85	0·392	822	558	
	55	0·818	71·5	0·399	813	549	65·9
	54·5	0·834	71·15	0·406	803	540	
	54	0·851	70·8	0·412	798	533	65·3
	53·5	0·869	70·4	0·421	788	526	
	53	0·887	70	0·429	785	521	64·7
	52·5	0·905	69·5	0·439	784	518	
57·75	52	0·923	69·14	0·447	777	510	64

Boil.-temp. °C.	Acetone in liquid a wt. %	f	Acetone in vapour a_d wt. %	f_d	$\frac{a+f\beta}{f-f_d}$	$\frac{a+f_d\beta}{f-f_d}$	Bergström a_d wt. %
	51·5	0·941	68·72	0·455	769	505	
58·02	51	0·964	68·3	0·464	760	496	63·2
	50·5	0·980	67·9	0·473	758	492	
58	50	1·000	67·5	0·482	732	487	62·3
	49·5	1·020	67·12	0·490	744	480	
	49	1·042	66·75	0·498	735	471	61·8
	48·5	1·062	66·38	0·507	729	466	
58·34	48	1·082	66	0·515	724	460	61·1
58·5	47·5	1·105	65·65	0·523	718	453	
	47	1·128	65·3	0·531	707	445	60·3
58·52	46·5	1·150	64·91	0·540	703	439	
	46	1·174	64·5	0·550	696	433	59·7
	45·5	1·198	64·25	0·556	691	422	
	45	1·222	63·8	0·567	685	420	58·8
	44·5	1·247	63·35	0·578	680	415	
58·8	44	1·273	62·9	0·590	673	410	58·6
	43·5	1·299	62·45	0·600	669	406	
	43	1·326	62	0·613	666	401	57·1
	42·5	1·353	61·5	0·626	663	400	
	42	1·381	61	0·639	661	396	56·3
58·96	41·5	1·410	60·7	0·648	653	389	
	41	1·439	60·2	0·661	652	387	55·9
	40·5	1·469	59·7	0·677	646	383	
	40	1·500	59·2	0·689	643	381	54·5
	39·5	1·531	58·75	0·702	641	376	
	39	1·564	58·3	0·715	634	370	53·6
	38·5	1·597	57·8	0·730	628	365	
59·5	38	1·632	57·3	0·745	628	364	52·8
	37·5	1·666	56·8	0·761	622	359	
	37	1·703	56·3	0·776	621	357	52
	36·5	1·739	55·8	0·792	620	355	
	36	1·778	55·3	0·808	612	349	51
	35·5	1·817	54·85	0·824	610	346	
	35	1·857	54·4	0·838	606	341	50
	34·5	1·899	53·9	0·855	603	338	
	34	1·941	53·4	0·873	599	334	49
	33·5	1·985	52·88	0·891	595	330	
	33	2·030	52·33	0·910	591	326	48
	32·5	2·077	51·8	0·930	591	325	
60·2	32	2·124	51·25	0·950	585	322	47
	31·5	2·174	50·65	0·974	583	319	
	31	2·225	50·1	0·996	581	317	46
	30·5	2·278	49·55	1·018	576	314	
	30	2·333	49	1·042	575	310	45

Boil.-temp. °C.	Acetone in liquid a wt. %	f	Acetone in vapour a_d wt. %	f_d	$\frac{a+f\beta}{f-f_d}$	$\frac{a+f_d\beta}{f-f_d}$	Bergström a_d wt. %
	29·5	2·389	48·5	1·062	572	305	
	29	2·448	48	1·083	566	303	44
	28·5	2·508	47·4	1·109	567	301	
	28	2·571	46·8	1·138	563	297	42·9
	27·5	2·636	46·15	1·166	560	295	
	27	2·704	45·5	1·198	558	294	41·8
	26·5	2·773	44·82	1·230	557	292	
	26	2·847	44·2	1·262	554	289	40·5
	25·5	2·941	43·6	1·294	552	285	
	25	3·000	43	1·326	550	284	39·4
	24·5	3·081	42·4	1·358	547	281	
	24	3·167	41·75	1·395	546	280	38·2
	23·5	3·255	41·15	1·430	541	275	
	23	3·398	40·5	1·469	540	275	36·9
	22·5	3·444	39·8	1·513	536	272	
	22	3·542	39·2	1·551	533	269	35·6
	21·5	3·651	38·6	1·591	533	265	
61·8	21	3·762	38	1·632	530	263	34·3
	20·5	3·878	37·2	1·688	527	261	
	20	4·000	36·5	1·739	524	259	33·1
61·98	19·5	4·128	35·8	1·793	522	256	
	19	4·266	35·2	1·841	517	252	31·8
	18·5	4·405	34·5	1·899	514	251	
	18	4·550	33·9	1·950	512	247	30·4
	17·5	4·714	33·2	2·012	506	243	
	17	4·882	32·5	2·077	505	240	28·1
	16·5	5·060	31·7	2·155	504	239	
	16	5·250	31	2·226	501	235	27·6
	15·5	5·451	30·4	2·285	496	231	
	15	5·66	29·5	2·389	495	230	26·2
	14·5	5·90	28·8	2·472	492	227	
	14	6·14	28·2	2·546	486	222	24·7
	13·5	6·40	27·6	2·623	480	216	
	13	6·69	27	2·704	475	210	23·2
	12·5	7·00	26·2	2·817	473	207	
	12	7·33	25·5	2·941	468	204	21·7
	11·5	7·70	24·75	3·045	464	199	
63·44	11	8·10	24	3·167	460	196	20·2
	10·5	8·53	23	3·348	459	194	
	10	9·00	22	3·542	459	193	18·6
	9·5	9·52	21	3·762	457	193	
	9	10·11	20·1	3·975	455	190	17
	8·5	10·80	19	4·266	451	187	
63·9	8	11·50	18·4	4·435	448	184	15·3

Boil.-temp. °C.	Acetone in liquid a wt. %	f	Acetone in vapour a_d wt. %	f_d	$\frac{a + f\beta}{f - f_d}$	$\frac{a + f_d\beta}{f - f_d}$	Bergström a_d wt. %
	7·5	12·33	17·4	4·747	445	182	
	7	13·29	16·5	5·060	441	178·5	13·6
	6·5	14·38	15·8	5·329	432	168·3	
	6	15·79	15	5·660	425	160·5	11·8
	5·5	17·18	14	6·143	419	158	
	5	19·20	13	6·692	416	151·2	10·1
	4·5	21·21	12	7·333	413	148	
	4	24	11	8·090	407	142·7	8·1
	3·5	27·51	10·1	8·900	397	133·1	
	3	32·33	9	10·111	390	126	6·2
	2·5	39	8	11·500	378	115	
	2	49	6·5	14·380	375	113	4·2
	1·5	65·66	5·2	18·231	369	104·2	
65·63	1	99	4	24	353	86·1	2·2
	0·5	199	2·1	46·619	346·8	81·4	1·1

TABLE 35

Acetone and Methyl Alcohol

Reflux heat C_R required in *rectifying columns* to produce 1 kg. acetone as 50, 60, 70% wt. vapour from mixtures of acetone and methyl alcohol containing from 52 to 0·5% acetone.

Acetone-content of		Heat needed to produce 1 kg. acetone as vapour of			Acetone-content of		Heat needed to produce 1 kg. acetone as vapour of			Heat C_a needed in *boiling-columns* to separate 100 kg. methyl alcohol as "run-off."
Liq.	Vap.	50% C_R	60% C_R	70% C_R	Liq.	Vap.	50% C_R	60% C_R	70% C_R	
wt. %	wt. %	kg. cal.	kg. cal.	kg. cal.	wt. %	wt. %	kg. cal.	kg. cal.	kg. cal.	kg. cal.
52	69·1	—	—	14·2	16	31·0	612	780	900	23,500
50	67·5	—	—	30·0	15	29·5	676	851	970	23,000
48	66·0	—	—	60·0	14	28·2	750	913	1,020	22,200
46	64·5	—	—	85	13	27·0	809	968	1,080	21,000
44	62·9	—	—	108	12	25·5	908	1,065	1,174	20,400
42	61·0	—	—	138	11	24·0	997	1,150	1,203	19,800
40	59·2	—	48	167	10	22·0	1,166	1,320	1,427	19,400
38	57·3	—	50	199	9	20·1	1,354	1,506	1,613	19,200
36	55·3	—	81	232	8	18·4	1,538	1,688	1,792	18,400
34	53·4	—	124	266	7	16·5	1,790	1,838	1,998	17,850
32	51·3	—	166	304	6	15·0	1,980	2,220	2,220	16,050
30	49·0	24·15	215	353	5	13·0	2,366	2,506	2,616	15,120
28	46·8	77·69	265	399	4	11·0	2,885	3,021	3,117	14,270
26	44·2	145·10	322	461	3	9·0	3,552	3,681	3,749	12,600
24	41·8	215	398	528	2	6·5	5,017	5,140	5,231	11,300
22	39·2	293	522	597	1	4·0	8,119	8,230	8,330	8,610
20	36·5	387	562	686	0·5	2·1	15,820	15,942	15,960	8,140
18	33·9	486	657	779						

TABLE 36

Acetone and Methyl Alcohol

Rectifying Columns

Acetone-content of liquid and vapour on each plate in rectifying columns when a final vapour containing 50, 60, 70% acetone (50, 40, 30% m. alcohol) is obtained with a heat-expenditure C_R ranging from 8,000 to 40,000 kg. cal. for 10 kg. acetone.

No. of plate from top.	Reflux heat C_R for 10 kg. acetone									
	8,000 kg. cal.		10,000 kg. cal.		20,000 kg. cal.		30,000 kg. cal.		40,000 kg. cal.	
	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %
The product contains 50% wt. acetone										
	31	50	31	50	31	50	31	50	31	50
1	20·6	37·95	20·95	36·63	18·5	34·5	17·75	33·95	17·4	33
2	16·5	31·55	14	28·1	11·5	24·75	10·4	22·6	9·4	20·75
3	14·5	29·05	11·9	25·95	8·6	19·1	6·6	16	5·5	14
4	14	28·1	11·5	24·7	7·48	16·83	4·75	13	3·8	10·6
5	13·7	27·6	11·2	24·20	6·7	16	4·2	11·25	2·95	7·15
The product contains 60% wt. acetone										
	41·5	60	41·5	60	41·5	60	41·5	60	41·5	60
1	28	46·75	26·1	44·3	25·5	43·5	25	43	24·4	42·6
2	21	38·25	19·5	36·6	16	31	14·75	29·3	13·73	27·95
3	18	34	16	31	10·7	23·45	9	20·2	7·9	18·1
4	17·5	32·1	14·5	28·9	8·7	19·4	6·75	15·2	4·8	12·7
5	17	32·1	13·7	27·75	7·7	17·6	4·6	12·8	3·4	10·1
6	16·25	32·06	13	13	7·2	16·8	4·25	11·6	2·95	8·9
The product contains 70% wt. acetone										
	53	70	53	70	53	70	53	70	53	70
1	38	57·25	37·4	56·7	35·8	55·4	35	54·5	34·7	54·15
2	28	46·75	26·5	45	23	40·5	21·75	38·7	20	36·5
3	22·4	40	20·5	37·5	15	29·6	12·5	26·1	11	24
4	20	36·5	18·2	34·1	10·6	23	8·25	18·75	6·6	16
5	18·5	34·7	16·25	31·5	8·75	19·4	5·9	14·75	4·5	11·8
6	18	34·2	15·3	30·4	7·85	18	4·75	12·8	3·5	9·95
7	15·4	33·8	15	29·4	7·4	17·2	4·4	11·75	3	9

TABLE 37

Acetone and Methyl Alcohol

Acetone-content of liquid and vapour on each plate in *boiling-columns* when the heat-expenditure C_a ranges from 10,000 to 50,000 kg. cal. for every 100 kg. of methyl alcohol separated at the base.

No. of plate from top.	Heat-expenditure C_a for 100 kg. methyl alcohol									
	10,000 kg. cal.		20,000 kg. cal.		30,000 kg. cal.		40,000 kg. cal.		50,000 kg. cal.	
	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %
n	1·45	5·1	11·7	25·4	28·4	47·3	42·5	61·5	51·25	68·5
—	—	—	—	—	—	—	—	—	—	—
20	—	—	—	—	—	—	—	—	50·01	67.6
19	0·0629	0·25	8·4	18·8	24·15	41·75	39·8	59	50	67·5
18	0·0573	0·229	8·25	18·6	23·1	41	39·3	59	49·4	66·9
17	0·0520	0·207	8·1	18·5	22·1	39·1	38·8	57·7	48	66
16	0·0440	0·176	7·6	17·5	20·8	37·1	37	56·3	46·5	64·91
15	0·0402	0·161	7·0	16·5	18·5	34·8	35·1	53	44	62·9
14	0·0367	0·147	6·0	15	16·2	22·95	33·3	52·1	40·5	59·7
13	0·0350	0·140	5·0	13	14·25	28·5	30·9	49	36·5	55·8
12	0·0318	0·127	4·0	11	12	25·5	27	45·5	31·75	50·65
11	0·0289	0·115	2·9	8·85	9·25	21·5	23	40·15	26·5	44·6
10	0·0259	0·104	2·4	7·9	7·6	17·2	17·2	33·3	20·75	37·5
9	0·0237	0·095	1·7	5·85	5·4	13·8	12·32	26·1	15·2	29·6
8	0·0215	0·086	1·0	4·0	3·45	10·0	8·6	19·6	10	22
7	0·0196	0·078	0·66	2·37	1·81	6·3	5·35	14	6·0	15
6	0·0179	0·0694	0·4	1·38	0·9	3·3	2·7	8·5	3·01	9
5	0·0163	0·0654	0·2	0·84	0·408	1·6	1·22	4·40	1·21	4·5
4	0·0148	0·0595	0·098	0·39	0·194	0·81	0·48	1·91	0·446	1·79
3	0·0135	0·0542	0·0571	0·220	0·091	0·39	0·140	0·54	0·171	0·680
2	0·0121	0·0493	0·0329	0·131	0·0424	0·169	0·0581	0·233	0·0653	0·260
1	0·0116	0·0467	0·0190	0·0763	0·0212	0·0847	0·0240	0·0962	0·0262	0·105
	0·01	0·04	0·01	0·04	0·01	0·04	0·01	0·04	0·01	0·04

TABLE 38 [1]

Conversion of volume-percentages into weight-percentages of ethyl alcohol in aqueous mixtures. Temperature, 15·5° C.

Vol. %	Wt. %	Vol. %	Wt. %	Vol. %	Wt. %	Vol. %	Wt. %	Vol. %	Wt. %
0·0	0·00	20·0	16·28	40·0	33·39	60·0	52·20	80·0	73·58
5	40	5	70	5	84	5	70	5	74·17
1·0	80	21·0	17·12	41·0	34·28	61·0	53·20	81·0	75
5	1·20	5	54	5	73	5	70	5	75·34
2·0	60	22·0	95	42·0	35·18	62·0	54·19	82·0	91
5	2·00	5	18·37	5	63	5	69	5	76·50
3·0	40	23·0	79	43·0	36·08	63·0	55·21	83·0	77·09
5	80	5	19·21	5	55	5	72	5	69
4·0	3·20	24·0	62	44·0	99	64·0	56·23	84·0	78·29
5	60	5	20·03	5	37·45	5	74	5	89
5·0	4·00	25·0	46	45·0	90	65·0	57·25	85·0	79·50
5	40	5	88	5	38·36	5	77	5	80·11
6·0	80	26·0	21·30	46·0	82	66·0	58·29	86·0	74
5	5·20	5	72	5	39·28	5	81	5	81 35
7·0	62	27·0	22·14	47·0	73	67·0	59·33	87·0	95
5	6·02	5	56	5	40·19	5	85	5	82·56
8·0	42	28·0	99	48·0	66	68·0	60·38	88·0	83·19
5	82	5	23·41	5	41·12	5	91	5	83
9·0	7·24	29·0	84	49·0	59	69·0	61·43	89·0	84·46
5	64	5	24·26	5	42·05	5	95	5	85·11
10·0	8·05	30·0	69	50·0	52	70·0	62·49	90·0	76
5	45	5	25·12	5	99	5	63·04	5	86·41
11·0	87	31·0	55	51·0	43·47	71·0	57	91·0	87·06
5	9·27	5	98	5	94	5	64·11	5	72
12·0	69	32·0	26·40	52·0	44·42	72·0	65	92·0	88·38
5	10·09	5	83	5	89	5	65·19	5	89·04
13·0	51	33·0	27·26	53·0	45·37	73·0	73	93·0	71
5	91	5	69	5	84	5	66·28	5	90·38
14·0	11·33	34·0	28·13	54·0	46·32	74·0	83	94·0	91·08
5	74	5	56	5	80	5	67·38	5	77
15·0	12·15	35·0	99	55·0	47·29	75·0	93	95·0	92·46
5	56	5	29·43	5	77	5	68·48	5	93·17
16·0	97	36·0	86	56·0	48·26	76·0	69·04	96·0	89
5	13·40	5	30·30	5	74	5	60	5	94·61
17·0	80	37·0	74	57·0	49·23	77·0	70·17	97·0	95·34
5	14·20	5	31·18	5	72	5	74	5	96·09
18·0	62	38·0	62	58·0	50·21	78·0	71·30	98·0	84
5	15·02	5	32·06	5	70	5	87	5	97·61
19·0	44	39·0	50	59·0	51·20	79·0	72·45	99·0	98·39
5	86	5	95	5	70	5	73·01		

[1] From Prof. Dr. M. Maercker's "Handbuch der Spiritusfabrikation."

TABLE 39

Methyl Alcohol and Ethyl Alcohol

Methyl-alcohol content of liquid mixtures of methyl and ethyl alcohols and of the vapours arising therefrom. Ratios of the liquids $\frac{a}{m} = f$, and of the vapours $\frac{a_d}{m_d} = f_d$.

Values of $\frac{\alpha + f\beta}{f - f_d}$ and $\frac{\alpha + f_d\beta}{f - f_d}$. $\alpha = 262$, $\beta = 234$

According to H. Bergström, amplified by the author.

Methyl alcohol m %	f	Methyl alcohol m_d %	f_d	$\frac{\alpha + f\beta}{f - f_d}$	$\frac{\alpha + f_d\beta}{f - f_d}$
100	0	100	0		
99	0·0101	99·3	0·0071	88,200	87,800
98·5	0·0152	99	0·0101	52,000	51,800
98	0·0204	98·7	0·0132	37,050	26,850
97	0·0309	98·2	0·0183	21,340	21,220
96·75	0·0336	98	0·0204	20,450	20,210
96	0·0417	97·4	0·0267	18,120	17,870
95·4	0·0482	97	0·0309	15,775	15,560
95	0·0526	96·8	0·0331	14,050	13,800
94	0·0638	96·2	0·0395	11,410	11,160
93·75	0·0666	96	0·0417	11,130	10,930
93	0·0753	95·5	0·0471	9,900	9,675
92·4	0·0823	95	0·0526	9,450	9,220
92	0·0870	94·7	0·0560	9,100	8,880
90·9	0·1001	94	0·0638	7,860	7,620
90	0·1111	93·4	0·0707	7,110	6,890
89·40	0·1186	93	0·0753	6,680	6,460
89	0·1236	92·7	0·0788	6,480	6,250
88	0·1364	92	0·0870	5,940	5,710
87	0·1494	91·3	0·0953	5,490	5,250
86·5	0·1561	91	0·0990	5,220	4,985
86	0·1628	90·6	0·1038	5,084	4,850
85·1	0·1751	90	0·1111	4,720	4,490
85	0·1765	89·9	0·1124	4,720	4,490
84	0·1905	89·2	0·1211	4,410	4,175
83·7	0·1947	89	0·1236	4,320	4,085
83	0·2048	88·5	0·1299	4,130	3,870
82·3	0·2151	88	0·1364	3,960	3,730
82	0·2195	87·8	0·1390	3,890	3,650
81	0·2346	87	0·1494	3,710	3,485
80	0·2500	86·3	0·1588	3,520	3,275
79·5	0·2579	86	0·1628	3,390	3,154
78·1	0·2804	85	0·1765	3,145	2,916
78	0·2821	84·9	0·1779	3,152	2,921
77	0·2987	84·2	0·1877	2,991	2,757
76·6	0·3055	84	0·1905	2.895	2,666

Methyl alcohol m %	f	Methyl alcohol m_d %	f_d	$\frac{\alpha + f\beta}{f - f_d}$	$\frac{\alpha + f_d\beta}{f - f_d}$
75	0·3333	82·8	0·2077	2715	2468
74	0·3514	82·1	0·2180	2576	2344
73·8	0·3550	82	0·2195	2566	2327
73	0·3699	81·4	0·2285	2491	2255
72·4	0·3812	81	0·2346	2395	2164
72	0·3889	80·7	0·2392	2360	2125
71	0·4085	80	0·2500	2243	2019
70	0·4286	79·3	0·2610	2161	1928
69·7	0·4347	79	0·2658	2152	1919
69	0·4493	78·5	0·2739	2092	1858
68·3	0·4641	78	0·2821	2035	1800
68	0·4706	77·8	0·2854	2005	1772
67·1	0·4903	77·1	0·2970	1950	1712
67	0·4925	77	0·2987	1932	1699
66	0·5152	76·3	0·3106	1872	1636
65·5	0·5267	76	0·3158	1824	1586
65	0·5385	75·6	0·3228	1800	1566
64·1	0·5601	75	0·3333	1733	1499
64	0·5652	74·9	0·3351	1716	1477
63	0·5873	74·1	0·3495	1681	1447
62·9	0·5898	74	0·3514	1677	1441
62	0·6129	73·4	0·3624	1616	1383
61·5	0·6260	73	0·3699	1594	1360
61	0·6393	72·5	0·3793	1582	1347
60·1	0·6639	72	0·3889	1516	1283
60	0·6667	71·9	0·3908	1513	1278
59	0·6949	71·1	0·4065	1470	1237
58·9	0·6978	71	0·4085	1470	1237
58	0·7241	70·3	0·4225	1429	1194
57·6	0·7361	70	0·4286	1413	1176
57	0·7544	69·5	0·4389	1389	1155
56·30	0·7762	69	0·4493	1357	1122
56	0·7857	68·7	0·4556	1350	1117
55·1	0·8149	68	0·4706	1351	1112
55	0·8182	67·9	0·4728	1311	1079
54	0·8519	67·1	0·4903	1274	1043
53	0·8868	66·2	0·5106	1248	1015
52·7	0·8975	66	0·5152	1233	1000
52	0·9231	65·4	0·5291	1212	976
51·6	0·9380	65	0·5385	1205	972
51	0·9608	64·5	0·5504	1183	951
50·5	0·9802	64	0·5625	1175	941
50	1·0000	63·6	0·5723	1157	924
49·4	1·0243	63	0·5873	1147	915
49	1·0408	62·7	0·5949	1134	900
48·3	1·0704	62	0·6129	1119	885
48	1·0833	61·7	0·6208	1113	880

Methyl alcohol m %	f	Methyl alcohol m_d %	f_d	$\frac{\alpha + f\beta}{f - f_d}$	$\frac{\alpha + f_d\beta}{f - f_d}$
47·3	1·1142	61	0·6393	1102	866
47	1·1277	60·7	0·6475	1093	861
46·3	1·1598	60	0·6667	1081	848
46	1·1739	59·7	0·6750	1075	840
45·4	1·2026	59	0·6949	1067	836
45	1·2222	58·6	0·7065	1061	828
44·5	1·2472	58	0·7241	1058	824
44	1·2727	57·5	0·7391	1050	818
43·6	1·2936	57	0·7544	1046	810
43	1·3256	56·4	0·7731	1035	802
42·7	1·3419	56	0·7857	1031	801
42	1·3810	55·2	0·8116	1024	793
41·8	1·3923	55	0·8182	1022	789
41	1·4390	54	0·8519	1018	784
40·2	1·4876	53	0·8868	1017	783
40	1·5000	52·8	0·8939	1012	777
39	1·5641	51·7	0·9342	998	764
38·5	1·5974	51	0·9608	996	764
38	1·6316	50·5	0·9802	991	756
37·6	1·6596	50	1·0000	988	753
37	1·7027	49·2	1·0325	982	749
36·8	1·7174	49	1·0408	981	745
36	1·7778	48	1·0833	974	741
35·2	1·8409	47	1·1277	971	737
35	1·8571	46·7	1·1413	970	736
34·4	1·9070	46	1·1739	969	734
34	1·9412	45·4	1·2026	968	734
33·6	1·9762	45	1·2222	962	725
33	2·0303	44·2	1·2624	958	722
32·8	2·0488	44	1·2727	953	720
32	2·1250	43	1·3256	945	720
31·1	2·2154	42	1·3810	940	715
31	2·2258	41·7	1·3981	939	710
30	2·3333	40·4	1·4753	938	707
29	2·4483	39	1·5641	937	709
28·2	2·5461	38	1·6316	935	703
28	2·5714	37·8	1·6455	933	698
27·4	2·6496	37	1·7027	930	694
27	2·7037	36·5	1·7397	929	692
26·6	2·7594	36	1·7778	925	690
26	2·8462	35·2	1·8409	923·2	688·5
25·8	2·8760	35	1·8571	917·2	682·7
25	3·0000	34	1·9412	911·0	676·0
24·3	3·1152	33	2·0303	915	678·5
24	3·1667	32·6	2·0675	910	677·9
23·6	3·2373	32	2·1250	918	674·8
23	3·3478	31·3	2·1949	907	672·7

Methyl alcohol m %	f	Methyl alcohol m_d %	f_d	$\frac{a+f\beta}{f-f_d}$	$\frac{a+f_d\beta}{f-f_d}$
22·8	3·3860	31	2·2258	909	670
22	3·5455	30	2·3333	900	667·4
21·2	3·7170	29	2·4483	890	665
21	3·7619	28·7	2·4843	892	660
20·5	3·8781	28	2·5714	894	661
20	4·0000	27·4	2·6496	886	653·5
19·7	4·0761	27	2·7037	885	651·7
19·1	4·2356	26·1	2·8314	891	657·8
19	4·2632	26	2·8462	888	654·4
18·3	4·4645	25	3·0000	892	658·4
18	4·5556	24·8	3·0323	872	637·9
17·4	4·7471	24	3·1667	866	632
17	4·8824	23·5	3·2553	862	628
16·6	5·0241	23	3·3478	857	623
16	5·2500	22·2	3·5045	850	619
15·8	5·3291	22	3·5455	847	611
15·1	5·6225	21	3·7619	846	612
15	5·6667	20·9	3·7847	842	609
14·4	5·9444	20	4·0000	842	616
14	6·1429	19·4	4·1546	840	609
13·6	6·3529	19	4·2632	838	603
13	6·6923	18·2	4·4945	831	598
12·8	6·8125	18	4·5556	821	587
12·1	7·2645	17	4·8824	823	588
12	7·3333	16·9	4·9172	823	583
11·4	7·7719	16	5·2500	823	590
11	8·0909	15·5	5·4516	816	581
10·6	8·4340	15	5·6667	808	566
10	9·0000	14·2	6·0423	800	565
9·9	9·101	14	6·1429	798	566
9·1	9·989	13	6·6923	789	555
9	10·111	12·9	6·7519	782	548
8·4	10·905	12	7·3333	789	555
8	11·506	11·5	7·6957	775	541
7·6	12·158	11	8·0909	760	530
7	13·286	10·1	8·9010	763	534
6·9	13·493	10	9·0000	753	527
6·1	15·393	9	10·1111	750	497
6	15·667	8·9	10·236	740	488
5·4	17·519	8	11·500	723	490
5	19·000	7·5	12·333	706	471
4·7	20·277	7	13·286	713	480
4	24·000	6	15·667	705	470
3·6	27·986	5	19·000	753	460
3	32·333	4·3	22·256	740	455
2·6	37·461	4	24·000	725	450
2	49·000	3	32·333	702	440
1	99·000	1·54	63·935	666	433
0·6	165·67	1	99·00	582	352

TABLE 40

Methyl and Ethyl Alcohols

Methyl-alcohol content of liquid and vapour on each plate in *rectifying columns* when 50–90% wt. vapour is produced with heat-expenditure C_R ranging from 60,000 to 100,000 kg. cal. for 1–10 kg. methyl alcohol.

No. of plate from top	Reflux heat C_R for 1—10 kg. methyl alcohol									
	For 1 kg. methyl alcohol 60,000 kg. cal.		For 10 kg. methyl alcohol 70,000 kg. cal.		For 1 kg. methyl alcohol 80,000 kg. cal.		For 1 kg. methyl alcohol 100,000 kg. cal.		For 10 kg. methyl alcohol 100,000 kg. cal.	
	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %
	37·6	50	85·1	90	37·6	50	37·6	50	85·1	90
1	28·1	37·6	79·45	85·6	28	37·8	27·8	37·6	78·7	85·4
2	20·95	28·4	71·6	80·2	20·7	28·2	20·4	27·8	69·9	79·1
3	15·15	21·15	61·35	72·65	15	20·9	14·7	20·5	58·3	70·5
4	11·19	15·4	49·25	62·8	11·1	15·25	11·1	16·1	45·7	59·4
5	7·95	11·4	39	51·59	78·5	11·35	7·7	11·28	35	46·7
6	5·79	8·3	30·45	41·15	5·65	8·10	5·25	7·9	27·1	36·6
7	4·10	6·11	24·25	32·9	3·98	5·98	3·68	5·45	21·1	28·9
8	3·29	4·45	19·6	26·7	3·0	4·29	2·60	3·9	16·6	22·9
9	2·35	3·5	16·1	22·2	2·25	3·32	1·86	2·9	11·8	15·8
10	1·65	2·75	13·5	18·95	1·65	2·52	1·35	2·10	9·5	13·5
11	1·25	2·05	11·55	16·4	1·27	1·96	1·02	1·58	8·1	11·5
12	1·05	1·63	10·2	14·5	1·03	1·57	0·81	1·26	7·2	70·25
13	0·927	1·44	9·25	13·15	0·98	1·31	0·67	1·04	6·3	9·4
14	0·854	1·32	8·7	12·4	0·73	1·13	0·58	0·91	5·7	8·5
15	0·800	1·24	8·2	11·7	0·64	1·00	0·525	0·81	5·4	7·95
16	0·763	1·18	7·5	10·9	0·60	0·94	0·49	0·76	5·1	7·5
17	0·735	1·14	6·5	10·5	—	—	0·46	0·72	4·9	7·3

Reflux heat C_R needed in rectifying columns to produce 1 kg. methyl alcohol as final product of 50 or 90% wt. from mixtures containing 80, 30, 0·6%.

Initial content of methyl alcohol	1 kg. methyl alcohol as 90% kg. cal.	1 kg. methyl alcohol as 50% kg. cal.	Initial content of methyl alcohol	1 kg. methyl alcohol as 90% kg. cal.	1 kg. methyl alcohol as 50% kg. cal.
80	532	—	15	2,425	2,344
70	548	—	10	4,830	4,032
60	580	—	5	8,650	7,970
50	652	—	4	11,033	10,300
40	896	—	3	17,360	16,600
30	1,385	445	2	26,960	21,970
25	1,762	858	1	41,700	31,960
20	2,425	1,461	0·6	57,550	57,000

TABLE 41

Methyl Alcohol and Ethyl Alcohol

Methyl-alcohol content of liquid and vapour on each plate in *boiling-columns* when the heat-expenditure C_a ranges from 50,000 to 100,000 kg. cal. for 100 kg. of ethyl alcohol run off at the base.

No. of plate from base	Heat-expenditure C_a for 100 kg. ethyl alcohol							
	50,000 kg. cal.		60,000 kg. cal.		80,000 kg. cal.		100,000 kg. cal.	
	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %
35	0·806	1·25	2·66	4·25	9·3	14·0	19·3	26·6
34	0·757	1·18	2·39	3·67	8·8	12·8	17·5	24·0
33	0·710	1·11	2·15	3·32	7·8	11·3	15·5	21·7
32	0·680	1·06	1·90	2·94	6·99	10·0	14·0	19·4
31	0·568	0·100	1·72	2·64	6·3	9·1	12·3	17·2
30	0·495	0·826	1·56	2·41	5·25	8·12	10·8	15·2
29	0·434	0·724	1·41	2·17	4·45	6·7	9·3	13·3
28	0·383	0·637	1·28	1·96	4·05	5·79	7·9	1·15
27	0·337	0·560	1·19	1·80	3·70	5·15	6·8	9·8
26	0·297	0·495	1·07	1·63	3·4	4·79	5·7	8·4
25	0·253	0·434	0·95	1·48	3·1	4·40	4·75	6·0
24	0·223	0·373	0·85	1·30	2·59	3·99	4·05	5·9
23	0·197	0·327	0·75	1·19	2·25	3·395	3·52	5·0
22	0·173	0·288	0·637	1·05	1·915	2·91	2·97	4·25
21	0·154	0·257	0·556	0·90	1·59	2·45	2·45	3·65
20	0·133	0·222	0·473	0·75	1·3	2·01	1·99	2·95
19	0·117	0·196	0·398	0·66	1·1	1·50	1·59	2·45
18	0·104	0·173	0·334	0·55	0·9	1·30	1·24	1·95
17	0·090	0·152	0·261	0·467	0·753	1·18	1·00	1·52
16	0·080	0·134	0·234	0·39	0·587	0·98	0·75	1·24
15	0·065	0·118	0·196	0·326	0·454	0·75	0·680	0·91
14	0·0624	0·105	0·166	0·276	0·354	0·588	0·505	0·833
13	0·0543	0·0906	0·140	0·233	0·278	0·458	0·371	0·617
12	0·0477	0·0797	0·116	0·193	0·215	0·357	0·274	0·458
11	0·0420	0·0700	0·0959	0·160	0·166	0·278	0·242	0·403
10	0·0363	0·0605	0·0796	0·132	0·129	0·215	0·180	0·298
9	0·0318	0·0531	0·0664	0·110	0·099	0·165	0·163	0·221
8	0·0279	0·0466	0·054	0·0918	0·077	0·129	0·102	0·163
7	0·0246	0·0409	0·0457	0·076	0·0598	0·100	0·073	0·120
6	0·0215	0·0359	0·0378	0·063	0·0461	0·077	0·053	0·0892
5	0·0190	0·0316	0·0317	0·0529	0·0357	0·0595	0·0393	0·0653
4	0·0165	0·0277	0·0207	0·0396	0·0277	0·0460	0·029	0·0483
3	0·0146	0·0244	0·0172	0·0287	0·0214	0·0357	0·0214	0·0358
2	0·0129	0·0215	0·0143	0·0239	0·0165	0·0275	0·0159	0·0264
1	0·0114	0·0190	0·012	0·0200	0·0120	0·0214	0·0125	0·0198
0	0·010	0·0166	0·010	0·0166	0·010	0·0166	0·010	0·0166

TABLE 42 (CHART III)

Water and Acetic Acid

Water-content of liquid mixtures of acetic acid and water and of the vapours arising therefrom. Ratios of liquids $\frac{e}{w} = f$, and of vapours $\frac{e_d}{w_d} = f_d$. Values of $\frac{\alpha + f\beta}{f - f_d}$ and $\frac{\alpha + f_d\beta}{f - f_d}$. $\alpha = 529{\cdot}0$, $\beta = 75{\cdot}5$

Percentage figures enclosed in [ ] are due to Lord Rayleigh (*Phil. Mag.* 1902, (6), 4, 521), and those in ( ) to C. Blacher (Riga, 1903); all others to H. Bergström (Stockholm, 1911). The last named have been extended by the author.

Boil.-temp. °C.	Water in liq. %	$\frac{e}{w} = f$	Water in vap. %	$\frac{e_d}{w_d} = f_d$	$\frac{\alpha + f\beta}{f - f_d}$	$\frac{\alpha + f_d\beta}{f - f_d}$	[Rayleigh] (Blacher)
100	100	0	100	0	0	0	
	99	0·0101	99·31	0·0069	165,500	165,300	
	98·51	0·0151	99	0·0101	106,000	106,000	
	98	0·0204	98·57	0·0145	90,000	90,000	
	97·22	0·0285	98	0·0204	65,520	65,520	
	97	0·0309	97·84	0·02204	59,472	59·472	
	96	0·04168	97·11	0·0297	44,690	44,610	
	95·85	0·0432	97	0·0309	43,250	43,070	
	95	0·0525	96·36	0·03778	36,240	36,170	
	94·51	0·0580	96	0·04168	32,680	32,630	
	94	0·0638	95·62	0·0458	29,660	29,540	[93·23—94·9]
	93·17	0·07335	95	0·0525	25,720	25,620	
	93	0·0752	94·87	0·05365	24,770	24,670	
	92	0·0869	94·12	0·0624	21,860	21,790	
	91·85	0·08875	94	0·0638	21,500	21,430	
	91	0·099	93·36	0·0711	19,200	19,140	
	90·53	0·1046	93	0·0752	18,250	18,190	
100·25	90	0·111	92·59	0·0801	17,370	17,300	
	89·20	0·1210	92	0·0869	15,760	15,700	
	89	0·123	91·85	0·0887	15,680	15,630	
	88	0·136	91·12	0·0974	13,960	13,880	
	87·85	0·1382	91	0·099	13,740	13,660	
	87	0·149	90·37	0·1065	12,700	12,620	
	86·50	0·1556	90	0·111	12,110	12,020	
	86	0·160	89·64	0·1116	11,170	11,080	
	85·15	0·174	89	0·123	10,600	10,500	
	85	0·176	88·89	0·1249	10,400	10,300	
	84	0·190	88·15	0·1344	9,770	9,700	
	83·80	0·193	88	0·136	9·530	9,440	

Boil.-temp. °C.	Water in liq. %	$\frac{e}{w} = f$	Water in vap. %	$\frac{e_d}{w_d} = f_d$	$\frac{\alpha + f\beta}{f - f_d}$	$\frac{\alpha + f_d\beta}{f - f_d}$	[Rayleigh] (Blacher)
	83	0·205	87·41	0·144	8920	8850	
	82·45	0·2129	87	0·149	8530	8440	
	82	0·219	86·67	0·1538	8355	8275	
	81·10	0·233	86	0·163	7820	7730	
	81	0·2344	85·93	0·1637	7730	7650	
100·45	80	0·250	85·19	0·1738	7170	7100	
	79·75	0·253	85	0·176	7100	7030	
	79	0·266	84·45	0·1841	6690	6620	
	78·40	0·2754	84	0·190	6430	6350	
	78	0·282	83·71	0·1949	6320	6250	
	77·05	0·2944	83	0·205	6150	6070	
	77	0·2989	82·97	0·2052	5875	5790	
	76	0·3159	82·24	0·2159	5530	5450	
	75·70	0·3210	82	0·219	5419	5350	
	75	0·333	81·48	0·2253	5152	5077	
	74·35	0·346	81	0·234	4956	4884	
	74	0·352	80·74	0·2384	4889	4819	[73·18—79·65]
	73	0·370	80·06	0·250	4639	4564	
	72	0·389	79·26	0·263	4430	4359	
	71·65	0·395	79	0·266	4332	4254	
	71	0·409	78·52	0·2734	4132	4059	
	70·30	0·422	78	0·282	4005	3927	
100·75	70	0·429	77·78	0·2855	3910	3840	
	69	0·449	77·04	0·2980	3720	3647	
	68·95	0·450	77	0·2987	3715	3647	
	68	0·472	76·30	0·310	3486	3405	
	67·60	0·479	76	0·3159	3465	3390	
	67	0·489	75·56	0·323	3407	3329	
	66·30	0·508	75	0·333	3238	3164	
	66	0·515	74·82	0·336	3183	3104	
	65	0·538	74·08	0·359	3032	2950	
	64·90	0·541	74	0·352	3024	2949	
	64	0·563	73·34	0·364	2865	2785	
	63·55	0·573	73	0·370	2813	2739	[63·54—71·9]
	63	0·587	72·60	0·377	2733	2656	
	62·20	0·608	72	0·389	2627	2550	
	62	0·613	71·86	0·392	2601	2529	(61·8—71·40)
	61	0·639	71·12	0·406	2475	2402	
	60·85	0·643	71	0·409	2468	2391	
101	60	0·666	70·37	0·421	2362	2288	
	59·50	0·680	70	0·429	2308	2232	
	59	0·695	69·63	0·436	2244	2171	
	58·15	0·720	69	0·449	2154	2080	
	58	0·724	68·89	0·452	2143	2066	
	57	0·754	68·15	0·467	2043	1965	
	56·80	0·760	68	0·472	1963	1892	

Boil.-temp. °C.	Water in liq. %	$\frac{e}{w} = f$	Water in vap. %	$\frac{e_d}{w_d} = f_d$	$\frac{a + f\beta}{f - f_d}$	$\frac{a + f_d\beta}{f - f_d}$	[Rayleigh] (Blacher)
	56	0·785	67·41	0·484	1896	1824	
	55·45	0·803	67	0·489	1875	1799	
101·25	55	0·818	66·67	0·500	1857	1782	
	54·10	0·848	66	0·515	1780	1705	
	54	0·851	65·93	0·517	1773	1698	
	53	0·887	65·19	0·544	1735	1659	
	52·75	0·897	65	0·548	1659	1587	
	52	0·923	64·45	0·551	1611	1535	
	51·39	0·946	64	0·563	1565	1488	
	51	0·961	63·71	0·570	1538	1461	[50·02—61·51]
101·50	50	1·000	63	0·587	1464	1386	
	49	1·041	62·11	0·610	1410	1334	
	48·88	1·047	62	0·613	1398	1322	
	48	1·082	61·21	0·634	1362	1286	
	47·76	1·095	61	0·639	1330	1255	
	47	1·128	60·31	0·658	1304	1230	
	46·64	1·145	60	0·666	1285	1210	
	46	1·174	59·45	0·682	1252	1177	
	45·51	1·197	59	0·695	1231	1156	
101·85	45	1·220	58·53	0·709	1206	1134	
	44·42	1·250	58	0·724	1181	1106	
	44	1·273	57·61	0·736	1162	1088	
	43·34	1·306	57	0·754	1134	1060	
	43	1·326	56·68	0·765	1119	1044	
	42·27	1·365	56	0·785	1090	1014	
	42	1·380	55·75	0·793	1079	1004	
	41·20	1·427	55	0·818	1044	969	
	41	1·439	54·81	0·824	1036	959	
	40·23	1·485	54	0·851	1012	936	
102·25	40	1·500	53·76	0·860	1000	926	
	39·26	1·548	53	0·887	975	899	
	39	1·564	52·73	0·895	964	888	[38·44—50·93]
	38·29	1·614	52	0·923	941	865	
	38	1·630	51·70	0·934	935	858	
	37·32	1·680	51	0·961	911	836	
	37	1·703	50·67	0·973	900	824	
	36·37	1·750	50	1·000	882	806	
	36	1·778	49·61	1·016	868	793	(35·6—48·08)
	35·44	1·823	49	1·041	851	774	
102·75	35	1·857	48·52	1·060	838	763	
	34·50	1·898	48	1·082	822	747	
	34	1·941	47·47	1·106	809	734	
	33·59	1·982	47	1·128	794	718	
	33	2·033	46·30	1·159	781	705	
	32·73	2·052	46	1·174	779	703	
	32	2·124	45·17	1·214	758	682	

Boil.-temp. °C.	Water in liq. %	$\frac{e}{w} = f$	Water in vap. %	$\frac{e_d}{w_d} = f_d$	$\frac{a + f\beta}{f - f_d}$	$\frac{a + f_d\beta}{f - f_d}$	[Rayleigh] (Blacher)
	31·85	2·143	45	1·222	749	673	
	31	2·225	44·01	1·271	731	656	
	30·10	2·320	43	1·326	704·5	630	
103·40	30	2·333	42·85	1·333	705·0	629	
	29·23	2·420	42	1·380	684·5	608·5	
	29	2·449	41·71	1·398	679·7	604·5	
	28·39	2·525	41	1·439	663·1	587·5	
	28	2·571	40·53	1·468	655·3	580·0	
	27·55	2·630	40	1·500	643·3	568·1	[27·73—39·55]
	27	2·704	39·30	1·544	631·8	556·8	
	26·73	2·744	39	1·564	623·7	548·3	
	26	2·847	38·05	1·629	611·5	535·5	
	25·12	2·983	37	1·703	588·8	513·1	
104	25	3·000	36·85	1·713	587·4	511·2	
	24·30	3·115	36	1·778	571·4	495·9	
	24	3·167	35·63	1·806	564·4	488·7	
	23·48	3·259	35	1·857	553·3	477·6	
	23	3·348	34·40	1·907	542·7	467·0	
	22·69	3·409	34	1·941	535·7	459·9	
	22	3·542	33·08	2·026	525·0	448·5	
	21·19	3·720	32	2·124	506·6	430·9	
	21	3·762	31·75	2·150	503·4	428·4	
	20·43	3·898	31	2·225	492·0	416·8	(20·31—30·33)
105	20	4·000	30·44	2·282	484·0	408·2	
	19·67	4·097	30	2·333	531·8	399·7	
	19	4·266	29·10	2·436	465·5	389·0	[18·34—26·94]
	18·28	4·470	28	2·571	456·0	380·2	
	18	4·550	27·76	2·604	448·7	372·6	
	17·44	4·735	27	2·704	435·0	359·9	
	17	4·882	26·39	2·796	429·6	354·4	
	16·72	4·987	26	2·847	423·5	347·7	
	16	5·250	25·01	2·999	410·7	335·2	
	15·29	5·548	24	3·167	398·1	322·5	
106·25	15	5·660	23·59	3·239	394·8	319·2	
	14·59	5·852	23	3·348	387·4	312·0	
	14	6·143	22	3·514	377·3	301·7	
	13·18	6·597	21	3·762	362·7	286·5	
	13	6·692	20·74	3·828	360·0	285·4	
	12·50	7·000	20	4·000	352·0	276·7	
	12	7·333	19·27	4·198	344·0	269·8	
	11·15	7·961	18	4·550	331·0	255·4	
	11	8·104	17·78	4·629	327·5	252·0	
	10·45	8·561	17	4·882	318·2	243·9	
108·50	10	9·000	16·30	5·135	313·0	237·5	[9·3—13·78]
	9·17	9·900	15	5·660	299·0	225·0	
	9	10·111	14·74	5·796	298·0	224·0	

Boil.-temp. °C.	Water in liq. %	$\frac{e}{w} = f$	Water in vap. %	$\frac{e_d}{w_d} = f_d$	$\frac{\alpha + f\beta}{f - f_d}$	$\frac{\alpha + f_d\beta}{f - f_d}$	[Rayleigh] (Blacher)
	8·51	10·750	14	6·143	290·7	215·4	
	8	11·500	13·22	6·568	283·0	207·0	
	7·20	12·880	12	7·333	275·0	194·4	
110	7	13,286	11·70	7·547	278·4	192·4	
	6·56	14,240	11	8·104	265·6	185·8	
111	6	15·790	10·18	8·898	245·9	171·6	
	5·33	17·703	9	10·111	244·6	169·0	
112	5	19·200	8·45	10·830	235·7	160·0	
	4·22	23·270	7	13·286	235·0	152·9	
113	4	24·000	6·80	13·700	228·1	151·4	(3·85—7·13)
	3·52	27·400	6	15·790	224·1	148·2	
114	3	32·333	5·14	18·450	213·8	138·2	
	2·32	42·100	4	24·000	204·7	130·2	
115	2	49·000	3·46	27·900	200·0	124·9	
	1·643	59·973	3	32·330	183·0	107·5	
116·5	1	99·000	2·17	45·080	148·0	72·5	
	0·922	107·499	2	49·000	147·5	72·1	
118	0·5	199·000	1·085	91·170	144·5	68·54	
	0·4	249·000	0·868	114·200	143·0	67·72	
	0·3	332·000	0·651	152·600	142·5	67·08	
	0·2	499·000	0·434	230·000	142·0	67·58	
	0·1	999·000	0·217	460·000	141·2	65·47	

TABLE 43 (CHART V)

Water and Acetic Acid

Reflux heat C_R needed in *rectifying columns* to produce 1 kg. water (99·9%) from mixtures of acetic acid and water containing 95—0·5 % water.			Heat of vaporisation C_a needed in *boiling-columns* to separate 100 kg. acetic acid from aqueous mixtures containing 95–0·5% water (or, heat needed to raise the water-content of the vapour from 1·085% below to 96·36% above, for 100 kg. of acetic acid discharged at the base).
Water-content of		Heat required to produce 1 kg. water of 99·9%. C_R kg. cal.	Heat needed to separate 100 kg. acetic acid. C_a kg. cal.
Liquid wt. %	Vapour wt. %		
95	96·36	1,368	3,617,000
90	92·59	1,385	1,730,000
85	88·89	1,320	1,050,000
80	85·19	1,245	710,000
70	77·78	1,116	384,000
60	70·37	993	228,800
55	66·67	929	178,200
50	63	859	138,600
45	58·53	853	113,400
40	53·76	860	92,600
35	48·52	888	76,300
30	42·85	940	63,000
25	36·85	1,005	51,120
20	30·44	1,105	40,820
15	23·59	1,275	31,920
12	19·27	1,443	26,980
10	16·30	1,606	23,750
8	13·22	1,858	20,700
6	10·12	2,188	17,160
4	6·8	3,120	15,140
3	5·14	3,920	13,820
2	3·46	5,580	12,490
1	2·17	6,670	8,250
0·5	1·085	13,020	6,854

TABLE 44

Water and Acetic Acid

Water-content of liquid and vapour on each plate in *rectifying columns* when vapour containing 99% water (1% acetic acid) is produced with a reflux-heat expenditure of 20,000 to 150,000 kg. cal. for every 10 kg. water.

Plates	Reflux heat C_R for 10 kg. water									
	20,000 kg. cal.		30,000 kg. cal.		50,000 kg. cal.		80,000 kg. cal.		150,000 kg. cal.	
	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %
	98·51	99	98·51	99	98·51	99	98·51	99	98·51	99
1	98·2	98·66	98·2	98·66	98·2	98·66	98·2	98·66	98·1	98·65
2	97·74	98·36	97·6	98·3	97·5	98·3	97·45	98·25	97·35	98·1
3	97·11	97·92	96·95	97·85	96·8	97·78	96·63	97·65	96·33	97·5
4	96·7	97·55	96·4	97·30	96·0	97·0	95·6	96·73	95·0	96·36
5	95·9	97·04	95·45	96·75	94·50	96·07	94·35	95·89	93·4	95·23
6	95·28	96·59	94·4	95·9	93·17	95·0	92·7	94·65	91·5	93·64
7	94·61	96·1	92·6	94·6	92·0	94·1	91·0	93·31	89·2	92·01
8	94·25	95·8	91·0	93·4	90·53	93·09	88·6	91·6	84·6	89·64
9	93·17	95·0	90·1	92·79	89·2	92·04	86	89·6	80·01	85·2
10	92·8	94·75	88·5	91·41	86·75	90·2	75·5	81·8	73·55	80·48
11	92·0	94·1	86·5	90·0	84·0	88·1	69·1	77·1	65·66	74·55
12	90·53	93·0	84·2	88·13	80·6	85·68	62·0	70·83	52·0	64·5
13	89·7	92·4	81·55	86·37	75·85	82·1	51·0	63·71	40·0	53·78
14	88·9	91·74	78·75	84·35	70·0	77·8	39·37	53·3	28·4	41·05
15	87·3	90·5	74·4	81·24	60·9	71·808	28·5	41·22	19·0	29·28
16	85·8	89·55	69·8	77·5	50·5	63·56	19·9	30·37	12·5	19·85
17	84·3	88·34	63·75	73·16	39·6	53·39	14·0	22·0	7·33	13·2
18	83·6	87·18	55·66	67·22	29·5	42·59	9·2	15·31	5·0	8·41
19	81·4	86·27	47·0	60·3	21·6	32·49	6·25	10·51	3·3	5·57
20	79·4	84·79	37·9	51·6	16·5	25·77	4·4	7·50	1·88	3·37
21	77·0	82·98	29·8	42·73	11·7	18·96	3·25	5·53	1·25	2·435
22	71·8	79·16	23·0	34·48	8·4	13·98	2·55	4·315	0·78	1·767
23	68·0	76·37	16·4	25·66	6·19	10·439	2·32	4·039	0·65	1·355
24	63·75	73·2	12·8	20·49	4·2	8·10	1·9	3·364	0·58	1·208
25	58·45	69·24	10·25	16·65	3·5	5·986	1·5	2·918	—	—
26	52·0	64·46	8·3	13·76	3·1	5·24	1·3	2·49	—	—
27	45·1	58·68	6·9	11·65	2·5	4·81	1·15	2·307	—	—
28	37·8	51·56	6·1	10·2	2·33	4·17	0·99	2·14	—	—
29	31·5	44·64	5·6	9·25	—	—	—	—	—	—
30	26·35	38·5	5·11	8·67	—	—	—	—	—	—
31	22	33·05	4·85	8·19	—	—	—	—	—	—

TABLE 45

Water and Acetic Acid

Water-content of liquid and vapour on each plate in *boiling-columns* when the heat-expenditure C_a ranges from 80,000 to 4,000,000 kg. cal. per 100 kg. acetic acid.

No. of plate from base	Heat-expenditure C_a for 100 kg. acetic acid run off at the base									
	80,000 kg. cal.		100,000 kg. cal.		150,000 kg. cal.		200,000 kg. cal.		300,000 kg. cal.	
	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %
14	34·4	47·7	40·2	54·05	50·0	63·0	56·0	67·4	63·55	73·0
13	33·2	46·63	38·8	52·7	48·9	61·8	54·5	66·8	62·2	71·9
12	31·4	44·5	36·9	50·7	46·3	79·8	52·0	64·45	59·7	70·25
11	28·9	41·5	33·75	47·25	42·8	56·4	47·75	61·0	56·0	67·4
10	25·7	37·7	30·8	43·9	38·0	52·0	43·3	57·0	49·75	62·78
9	22·1	33·0	26·2	38·1	31·8	45·0	36·4	50·0	41·2	55·0
8	17·95	27·7	21·1	32·0	25·2	37·0	28·5	41·1	31·9	45·0
7	13·7	21·5	15·95	25·0	18·5	28·5	20·95	31·6	23·0	34·3
6	10·0	16·2	11·4	18·3	12·9	20·65	14·4	22·8	15·5	24·4
5	6·85	11·5	7·8	12·9	8·7	14·2	9·35	15·35	10·0	16·3
4	4·58	7·70	5·1	8·65	5·5	9·3	5·9	9·9	6·19	10·3
3	2·99	5·08	3·3	5·51	3·45	5·85	3·65	6·2	3·78	6·3
2	1·95	3·31	2·01	3·5	2·10	3·62	2·20	3·8	2·22	3·85
1	1·05	2·20	1·06	2·22	1·07	2·25	1·08	2·25	1·075	2·30
	0·5	1·085	0·5	1·085	0·5	1·085	0·5	1·085	0·5	1·085

	400,000 kg. cal.		700,000 kg. cal.		1,000,000 kg. cal.		2,000,000 kg. cal.		4,000,000 kg. cal.	
15	69·2	77·0	77·4	83·0	81·0	85·9	86·0	89·9	91·6	93·6
14	68·0	76·4	76·0	82·3	79·5	85·8	84·0	88·2	89·8	92·4
13	66·25	75·0	73·9	80·8	77·3	83·0	81·1	86·0	88·0	91·0
12	63·8	73·3	70·7	78·3	73·85	80·7	77·4	83·0	85·2	89·1
11	59·0	69·9	65·8	74·8	68·3	76·9	71·7	78·9	81·5	86·2
10	52·8	64·6	58·7	69·4	60·6	71·0	63·8	73·3	76·7	82·6
9	43·9	57·1	48·4	61·5	49·7	62·5	52·1	65·1	54·3	66·9
8	33·6	44·8	36·5	50·4	37·3	51·2	39·2	53·1	41·1	55·1
7	23·9	35·5	25·6	37·7	26·2	38·4	27·2	39·7	28·6	41·4
6	18·95	24·9	17·0	26·4	17·3	26·7	17·8	27·6	18·7	28·7
5	10·15	16·4	10·7	17·35	10·8	17·55	11·0	17·9	11·6	18 75
4	6·2	10·4	6·4	10·85	6·5	10·9	6·6	11·0	6·95	11·7
3	3·71	6·3	3·85	6·5	3·9	6·6	3·9	6·7	3·9	6·7
2	2·28	3·79	2·30	3·85	2·38	3·9	2·38	3·9	2·38	3·9
1	1·085	2·24	1·085	2·25	1·085	2·25	1·085	2·25	1·085	2·25
	0·5	1·085	0·5	1·085	0·5	1·085	0·5	1·085	0·5	1·085

TABLE 46 (CHART III)

Water and Formic Acid

Water-content of liquid mixtures of water and formic acid and of the vapours arising therefrom. Ratios of liquids $\frac{a}{w} = f$, and of vapours $\frac{a_d}{w_d} = f_d$. Values of $\frac{\alpha + f\beta}{f - f_d}$ and $\frac{\alpha + f_d\beta}{f - f_d}$.

$\alpha = 537{\cdot}0$
$\beta = 103{\cdot}7$

Values by H. Bergström, extended by the author.

Boil.-temp. °C.	Water in liquid. wt. %	$\frac{a}{w} = f$	Water in vapour. wt. %	$\frac{a_d}{w_d} = f_d$	$\frac{\alpha + f\beta}{f - f_d}$	$\frac{\alpha + f_d\beta}{f - f_d}$	Boil.-temp. ° C.	Water in liquid. wt. %	$\frac{a}{w} = f$	Water in vapour. wt. %	$\frac{a_d}{w_d} = f_d$	$\frac{\alpha + f\beta}{f - f_d}$	$\frac{\alpha + f_d\beta}{f - f_d}$
	99·5	0·00503	99·8	0·00200	178,457	178,457		74·5	0·3422	86·63	0·1543	3,043	2,941
	99	0·0101	99·6	0·00402	88,172	88,150		74	0·3520	86·26	0·1594	2,982	2,884
	98·5	0·0153	99·4	0·00604	58,131	58,091		73·5	0·3604	85·89	0·1644	2,930	2,827
	98	0·0204	99·2	0·00806	47,871	47,810		73	0·3700	85·52	0·1693	2,871	2,767
	97·5	0·0257	98·95	0·01061	35,711	35,628		72·5	0·3792	85·15	0·1742	2,811	2,707
	97	0·0309	98·7	0·01316	30,519	30,412		72	0·3890	84·78	0·1796	2,760	2,660
	96·5	0·0363	98·45	0·01575	26,250	26,146		71·5	0·3974	84·41	0·1846	2,718	2,613
	96	0·0417	98·2	0·01830	23,168	23,060		71	0·4090	84·04	0·1899	2,645	2,555
	95·5	0·0471	97·95	0·02093	20,684	20,576		70·5	0·4183	83·67	0·1951	2,603	2,498
	95	0·0525	97·7	0·02353	18,723	18,617		70	0·4290	83·30	0·2004	2,544	2,458
	94·5	0·0582	97·46	0·02606	16,887	16,784		69·5	0·4388	82·92	0·2060	2,504	2,399
	94	0·0638	97·22	0·02858	15,442	15,340		69	0·4490	82·54	0·2116	2,460	2,353
	93·5	0·0695	96·98	0·03116	14,149	14,043		68·5	0·4599	82·16	0·2171	2,412	2,308
	93	0·0752	96·74	0·03409	13,223	13,153		68	0·4706	81·78	0·2255	2,349	2,247
	92·5	0·0811	96·50	0·03626	12,162	12,057		67·5	0·481	81·40	0·228	2,324	2,220
	92	0·0869	96·26	0·03886	11,351	11,247		67	0·493	81	0·235	2,279	2,175
	91·5	0·0929	96·02	0·04071	10,500	10,364		66·5	0·503	80·60	0·241	2,248	2,140
	91	0·0990	95·78	0·04405	9,953	9,850		66	0·515	80·20	0·247	2,203	2,095
	90·5	0·1049	95·54	0·04665	9,396	9,291		65·5	0·526	79·80	0·253	2,171	2,066

90	0·1110	95·30	0·04931	8,906	8,784
89·5	0·1173	95·06	0·05197	8,409	8,305
89	0·1230	94·82	0·05459	8,036	7,930
88·5	0·1299	94·58	0·05729	7,578	7,484
88	0·1360	94·34	0·06030	7,280	7,174
87·5	0·1427	94·10	0·06265	6,897	6,709
87	0·1490	93·84	0·06567	6,691	6,524
86·5	0·1558	93·58	0·06856	6,318	6,239
86	0·1600	93·32	0·07154	6,255	6,147
85·5	0·1695	93·06	0·07460	5,843	5,740
85	0·1760	92·80	0·07754	5,638	5,534
84·5	0·1833	92·53	0·08079	5,421	5,325
84	0·1900	92·25	0·08399	5,251	5,151
83·5	0·1975	91·98	0·08720	5,068	4,963
83	0·2050	91·70	0·0904	4,873	4,769
82·5	0·2121	91·43	0·0937	4,720	4,616
82	0·2190	91·14	0·0972	4,595	4,491
81·5	0·2269	90·86	0·1007	4,448	4,344
81	0·2340	90·57	0·1041	4,307	4,208
80·5	0·2422	90·29	0·1076	4,175	4,072
80	0·2500	90	0·1110	4,044	3,953
79·5	0·2576	89·71	0·1146	3,940	3,834
79	0·2660	89·43	0·1183	3,822	3,703
78·5	0·2736	89·14	0·1218	3,726	3,621
78	0·2820	88·86	0·1254	3,623	3,509
77·5	0·2902	88·57	0·1290	3,522	3,418
77	0·2987	88·26	0·1331	3,435	3,339
76·5	0·3067	87·94	0·1371	3,375	3,271
76	0·3159	87·63	0·1412	3,252	3,176
75·5	0·3243	87·31	0·1453	3,187	3,083
75	0·3330	87	0·1490	3,096	3,012

65	0·538	79·40	0·260	2,140	2,035
64·5	0·550	79·02	0·266	2,099	1,995
64	0·563	78·64	0·272	2,046	1,941
63·5	0·573	78·26	0·278	2,021	1,917
63	0·587	77·88	0·284	1,979	1,868
62·5	0·600	77·50	0·290	1,935	1,831
62	0·613	77	0·299	1,912	1,808
61·5	0·626	76·50	0·307	1,886	1,780
61	0·639	76	0·316	1,831	1,761
60·5	0·652	75·50	0·324	1,820	1,740
60	0·666	75	0·333	1,799	1,717
59·5	0·680	74·50	0·342	1,776	1,695
59	0·695	74	0·352	1,752	1,671
58·5	0·709	73·50	0·360	1,729	1,647
58	0·724	73	0·370	1,717	1,615
57·5	0·739	72·50	0·379	1,707	1,603
57	0·754	71·94	0·399	1,689	1,586
56·5	0·770	71·38	0·401	1,671	1,567
56	0·785	70·82	0·412	1,648	1,554
55·5	0·801	70·26	0·423	1,644	1,540
55	0·818	69·70	0·435	1,623	1,520
54·5	0·834	69·08	0·448	1,614	1,510
54	0·851	68·46	0·461	1,613	1,499
53·5	0·869	67·84	0·474	1,589	1,494
53	0·887	67·22	0·488	1,579	1,474
52·5	0·904	66·60	0·501	1,564	1,461
52	0·923	65·94	0·516	1,559	1,453
51·5	0·941	65·28	0·5319	1,552	1,447
51	0·961	64·62	0·5477	1,541	1,437
50·5	0·980	63·96	0·5633	1,531	1,428
50	1·000	63·30	0·5795	1,526	1,421

Boil.-temp. °C.	Water in liquid. wt. %	$\frac{a}{w}=f$	Water in vapour wt. %	$\frac{a_d}{w_d}=f_d$	$\frac{a+f\beta}{f-f_d}$	$\frac{a+f_d\beta}{f-f_d}$	Boil.-temp. °C.	Water in liquid. wt. %	$\frac{a}{w}=f$	Water in vapour wt. %	$\frac{a_d}{w_d}=f_d$	$\frac{a+f\beta}{f-f_d}$	$\frac{a+f_d\beta}{f-f_d}$
	49·5	1·020	62·63	0·5964	1,516	1,413		37	1,703	44·64	1·2395	1,541	1,437
	49	1·042	61·96	0·6139	1,507	1,402		36·5	1·739	43·88	1·2789	1,556	1,455
	48·5	1·062	61·29	0·6320	1,503	1,401		36	1·778	43·12	1·3196	1,575	1,471
	48	1·082	60·62	0·6498	1,502	1,398		35·5	1·817	42·36	1·360	1,586	1,483
	47·5	1·105	59·95	0·6672	1,469	1,385		35	1·857	41·60	1·404	1,610	1,506
	47	1·128	59·28	0·6873	1,484	1,381		34·5	1·898	40·80	1·448	1,630	1,526
	46·5	1·150	58·61	0·7061	1,477	1,377		34	1·940	40	1·500	1,677	1,573
	46	1·174	57·94	0·7253	1,469	1,365		33·5	1·985	39·20	1·551	1,710	1,607
	45·5	1·198	57·27	0·7462	1,463	1,361		33	2·033	38·40	1·604	1,741	1,639
	45	1·222	56·60	0·7664	1,450	1,359		32·5	2·077	37·60	1·659	1,765	1,696
	44·5	1·247	55·86	0·7901	1,459	1,354		32	2·125	36·80	1·717	1,849	1,755
	44	1·273	55·12	0·8140	1,457	1,353		31·5	2·174	36	1·777	1,920	1,816
	43·5	1·299	54·38	0·8394	1,460	1,358		31	2·226	35·20	1·840	1,989	1,884
	43	1·325	53·64	0·8631	1,460	1,355		30·5	2·278	34·40	1·907	2,084	2,050
	42·5	1·353	52·90	0·8901	1,462	1,358		30	2·333	33·60	1·976	2,182	2,078
	42	1·381	52·16	0·9176	1,467	1,363		29·5	2·389	32·82	2·048	2,298	2,193
	41·5	1·410	51·42	0·9449	1,471	1,361		29	2·449	32·04	2·124	2,433	2,328
	41	1·439	50·68	0·9736	1,473	1,371		28·5	2·508	31·26	2·203	2,593	2,508
	40·5	1·469	49·94	1·0012	1,478	1,371		28	2·571	30·48	2·279	2,756	2,651
	40	1·500	49·20	1·0320	1,486	1,382		27·5	2·636	29·70	2·367	3,012	2,908
	39·5	1·531	48·44	1·0647	1,492	1,388		27	2·704	28·92	2·459	3,339	3,236
	39	1·564	47·68	1·0987	1,503	1,399		26·5	2·773	28·14	2·557	3,817	3,713
	38·5	1·597	46·92	1·1216	1,511	1,408		26	2·847	27·36	2·655	4,334	4,260
	38	1·632	46·16	1·1662	1,529	1,416		25·5	2·941	26·58	2·764	4,756	4,652
	37·5	1·666	45·40	1·2010	1,528	1,424		25	3,000	25·80	2·876	6,830	6,729

TABLE 47 (CHART XIV)

Formic Acid and Water

Reflux heat required in *rectifying columns* to produce 1 kg. water as vapour of 99·6% (formic acid 0·4%) from mixtures containing 99·0—25% formic acid.

Water in liq. wt. %	Water in vap. wt. %	Reflux-heat C_R. kg. cal.	Water in liq. wt. %	Water in vap. wt. %	Reflux-heat C_R. kg. cal.
99	99·6	177·4	45	56·6	1108·4
95	97·7	402·9	40	49·2	1530·6
90	95·3	421·2	35	41·6	2257·0
85	92·8	425·8	33	38·4	2788·6
80	90	440·7	30	33·6	4306·5
75	87	455·0	29	32·04	5162·6
70	83·3	504·5	28	30·48	6275·9
65	79·4	553·4	27	28·92	8204·2
60	75	595·5	26	27·36	11498·1
55	69·7	702·0	25	25·8	19630·0
50	63·3	880·7			

TABLE 48 (CHART XIV)

Formic Acid and Water

Heat needed in *boiling-columns* to separate 100 kg. formic acid containing 95–26% water (or, heat needed to obtain mixtures with from 26 to 95% water, for every 100 kg. of formic acid run off below).

Water in liq. wt. %	Heat C_a for 100 kg. formic acid. kg. cal.	Water in liq. wt. %	Heat C_a for 100 kg. formic acid. kg. cal.
95	1,861,700	45	135,300
90	878,400	40	138,000
85	553,400	35	151,640
80	390,000	33	163,938
75	301,000	30	207,800
70	245,000	29	232,810
65	203,500	28	265,140
60	171,700	27	323,690
55	152,000	26	426,060
50	142,100	25	672,900

TABLE 49

Water and Formic Acid

Water-content of liquid and vapour on each plate of *rectifying columns* in producing vapour containing 99·8% water (0·2% formic acid) with heat-expenditure C_R ranging from 5,000 to 200,000 kg. for 10 kg. water.

No. of plate from top	Reflux heat C_R for 100 kg. water									
	5,000 kg. cal.		15,000 kg. cal.		50,000 kg. cal.		100,000 kg. cal.		200,000 kg. cal.	
	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %
	99·5	99·8	99·5	99·8	99·5	99·8	99·5	99·8	99·5	99·8
1	98·75	99·5	98·75	99·5	98·7	99·48	98·7	99·48	98·7	99·47
2	98·5	99·42	97·75	99·1	97·5	98·94	97·35	98·87	97·25	98·83
3	97·75	99·1	97	98·72	95·2	97·8	94·8	97·62	94·1	97·27
4	97·3	98·81	95·2	97·77	90·25	95·45	89·25	94·91	88	94·3
5	97·0	98·7	90·5	95·58	83·5	91·99	79·6	89·83	77·4	88·51
6	96·5	98·42	82·8	91·6	72·5	85·2	66·5	80·5	63	77·99
7	95·9	98·16	74·9	86·9	60	75·07	54·2	68·36	50·25	63·6
8	95·5	98	66·5	80·57	49·7	62·92	45	56·61	41·5	50·4
9	94·8	97·61	58·5	73·5	42·75	53·13	38·25	46·6	35·5	42·36
10	94·25	97·35	53·8	68·36	37·9	45·96	35	41·3	31·7	36·3
11	93·6	97·05	46	57·96	34·6	41·07	31·8	36·66	29·25	32·46
12	93·4	96·9	44	55·11	32·6	37·73	29·8	33·49	27·75	30·13
13	—	—	43·8	54·8	31·7	36·5	28·75	31·5	26·75	28·52
14	—	—	42·65	53·18	30·9	35·1	28	30·42	26·2	27·77
15	—	—	—	—	30·4	34·1	27·5	29·7	25·6	27

TABLE 50

Water and Formic Acid

Water-content of liquid and vapour on each plate in *boiling-columns* when the heat-expenditure C_a ranges from 150,000 to 700,000 kg. cal. for 100 kg. formic acid run off at the base.

No. of plate from base	Heat-expenditure C_a for 100 kg. formic acid									
	150,000 kg. cal.		200,000 kg. cal.		300,000 kg. cal.		500,000 kg. cal.		700,000 kg. cal.	
	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %
20	51·29	64·95	—	—	—	—	—	—	87·02	93·84
19	50·8	64·33	—	—	74·32	86·38	83·3	91·8	86·28	93·43
18	49·78	62·96	—	—	73·8	86	83·12	91·77	84·17	92·27
17	49.1	62·1	—	—	72·14	85·07	82·44	91·33	79·82	89·9
16	48·47	61·25	—	—	69·82	83·25	81·17	90·6	72·1	84·8
15	47·86	60·33	64·4	78·82	66·35	80·4	79·68	89·8	61·65	76·65
14	47·05	59·28	62·62	77·6	60·9	75·9	75·4	87·25	52·65	66·33
13	46·33	58·3	61·2	76·2	54·5	69·08	69·08	82·54	44·29	55·29
12	45·43	57	59·78	74·25	49·21	61·25	60·1	75	38·09	46·16
11	44·56	55·86	57·25	72·28	43·79	54·75	51·16	64·85	33·78	39·6
10	43·7	54·68	54·3	68·75	39·49	48·4	43·73	54·7	30·91	35
9	42·95	53·5	51·14	64·78	36·29	43·2	38·21	46·44	28·94	31·98
8	42·19	52·44	47·9	60·5	33·8	39·6	34·2	40·3	27·63	29·9
7	41·49	51·4	44·7	56·2	32	36·8	31·46	36	26·86	28·72
6	40·9	50·5	42·08	52·16	30·75	34·8	30	33·6	26·13	27·75
5	40·3	49·3	39·75	48·8	29·81	33·3	28·67	31·33	25·75	26·98
4	39·7	48·75	37·66	45·75	29·12	32·3	27·91	30·8	25·36	26·76
3	39·2	47·96	36·1	43·13	28·69	31·52	27·19	29·2	25·2	26·54
2	38·77	47·3	34·75	41·2	28·5	31·26	26·57	28·33	25·09	26·30
1	38·41	46·7	33·8	39·48	28·26	30·88	26·23	27·6	25·03	26·06
	37·8	46·16	33	38·4	28	30·48	26	27·36	25	25·8

TABLE 51 (CHART III). Ammonia and Water.

Ammonia-content of liquid ammonia-water mixtures and of the vapours arising from them; ratios of liquids $\frac{w}{a} = f$, and of the vapours $\frac{w_d}{a_d} = f_d$; values of $\frac{\alpha + f\beta}{f - f_d}$ and $\frac{\alpha + f_d\beta}{f - f_d}$.

$\alpha = 450$
$\beta = 536$

Percentage figures according to Lord Raleigh (amplified by the author).

Ammonia in liquid. %	f	Ammonia in vapour. %	f_d	$\frac{\alpha + f\beta}{f - f_d}$	$\frac{\alpha + f_d\beta}{f - f_d}$	Ammonia in liquid. %	f	Ammonia in vapour. %	f_d	$\frac{\alpha + f\beta}{f - f_d}$	$\frac{\alpha + f_d\beta}{f - f_d}$
80	0·250	99	0·010	2435	1880	6·05	15·528	44	1·273	615	79
70	0·428	98	0·020	1697	1150	5·9	15·949	43	1·320	614	79
60	0·666	97	0·021	1266	733	5·75	16·391	42	1·381	614	79
48	1·083	96	0·042	988	454	5·60	16·857	41	1·439	614	78·8
41	1·439	95	0·053	810	347	5·46	17·348	40	1·500	614	78·7
34·6	1·890	94	0·064	800	265	5·30	17·868	39	1·564	613	78·7
28·2	2·546	93	0·075	731	198	5·15	18·417	38	1·632	613	78·6
25	3	92	0·087	705	170	5	19·200	37	1·703	613	78·5
22·5	3·444	91	0·099	684	150	4·85	19·610	36	1·778	613	78·4
20	4	90	0·111	665	131	4·7	20·270	35	1·857	613	78·3
19	4·263	89	0·124	657	124	4·56	20·920	34	1·940	613	78·2
18	4·555	88	0·136	653	118	4·42	21·620	33	2·033	613	78·1
17	4·882	87	0·149	650	114	4·28	22·360	32	2·105	612	78
16	5·250	86	0·163	646	107	4·14	23·150	31	2·220	612	77·9
15	5·666	85	0·176	634	99	4	24	30	2·333	612	77·8
14·5	5·896	84	0·190	630	97	3·84	25·078	29	2·449	612	77·7
14	6·142	83	0·204	628	94	3·68	26·170	28	2·571	612	77
13·62	6·350	82	0·219	627	92	3·52	27·400	27	2·704	611	76·6
13·25	6·550	81	0·234	626	91	3·36	28·760	26	2·847	611	76·2
12·89	6·760	80	0·250	626	90	3·2	30·251	25	3	611	76
12·66	6·902	79	0·265	626	89·3	3·066	31·745	24	3·167	610	75·7
12·44	7·030	78	0·282	625	88·9	3	32·333	23·5	3·255	609	75·4
12·22	7·193	77	0·299	624	88·2	2·929	33·198	23	3·348	609	75·2

12	7·333	76	0·316	624	87·8	2·786	34·899	22	3·542	608	75
11·8	7·474	75	0·333	624	87·5	2·643	36·869	21	3·762	608	74·8
11·6	7·621	74	0·351	623	87·4	2·50	39	20	4	607	74·6
11·4	7·771	73	0·380	623	87·2	2·399	40·700	19	4·27	607	74·4
11·2	7·928	72	0·389	623	87	2·266	43·100	18	4·55	606	74·2
11	8·091	71	0·408	622	86·5	2·133	45·800	17	4·88	606	74
10·75	8·306	70	0·428	622	86	2	49	16·25	5·151	606	73
10·5	8·523	69	0·449	621	85·6	1·962	50	16	5·25	606	72·5
10·25	8·753	68	0·470	621	85	1·81	54·2	15	5·66	605	72
10	9	67	0·492	621	84·5	1·688	58·4	14	6·13	605	71·9
9·858	9·152	66	0·515	620	84·2	1·560	63	13	6·69	605	71·8
9·715	9·290	65	0·538	619	84·1	1·444	68·50	12	7·33	604	71·6
9·562	9·460	64	0·562	619	84·1	1·322	74·70	11	8·09	604	71·7
9·409	9·627	63	0·587	619	84·1	1·20	82·30	10	9	603	71·6
9·256	9·810	62	0·613	619	84·1	1·066	93	9	10·11	603	71
8·980	10·136	61	0·639	618	83·5	1	99	8·5	10·76	602	69·4
8·760	10·415	60	0·666	618	83	0·933	106·1	8	11·50	602	68·8
8·543	10·709	59	0·695	618	82·4	0·80	124	7	13·19	602	67·7
8·326	11·010	58	0·724	617	82	0·675	147·1	6	15·79	600	66·9
8·109	11·345	57	0·754	617	81·8	0·60	165·70	5·4	17·54	600	66
7·922	11·625	56	0·785	617	81·7	0·55	180·8	5	19·20	600	65·6
7·769	11·880	55	0·818	617	81·6	0·455	228·8	4	24	598	65
7·615	12·140	54	0·852	617	81·3	0·4	249	3·7	26·03	598	64·3
7·48	12·369	53	0·887	616	81	0·313	319	3	32·33	596	62·1
7·32	12·661	52	0·923	616	80·7	0·3	332	2·9	33·45	596	61·3
7·16	12·966	51	0·961	616	80·4	0·2	499	2	49	596	59·8
7	13·286	50	1	616	79·9	0·15	666	1·5	65·58	595	59·8
6·84	13·620	49	1·040	615	79·9	0·10	999	1	99	595	59·6
6·68	13·970	48	1·083	615	79·9	0·075	1333	0·75	132·30	595	59·4
6·52	14·337	47	1·128	615	79·5	0·050	1999	0·50	199	594	59·4
6·36	14·723	46	1·174	615	79·5	0·025	3999	0·25	399	594	59·4
6·2	15·129	45	1·222	615	79	0·010	9999	0·1	999	59·3	59·4

TABLE 52 (CHART XIV)

Ammonia and Water

Reflux-heat requirement C_R in *rectifying columns* to produce 1 kg. ammonia-water vapour containing 20, 25, 30% wt. ammonia from aqueous mixtures of 4·0—0·1% wt.

Ammonia-content		Heat needed to produce 1 kg. ammonia as vapour of			Ammonia-content		Heat needed to produce 1 kg. ammonia as vapour of		
Liq. wt. %	Vap. wt. %	20% C_R kg. cal.	25% C_R kg. cal.	30% C_R kg. cal.	Liq. wt. %	Vap. wt. %	20% C_R kg. cal.	25% C_R kg. cal.	30% C_R kg. cal.
4	30	—	—	—	1·2	10	3,015	3,618	4,010
3·52	27	—	—	227	1	8·7	4,063	4,671	5,074
3	23·5	—	1552	561	0·8	7	5,532	6,135	6,530
2·79	22	—	329·5	736	0·6	5·4	8,100	8,700	9,120
2·5	20	—	607	1007	0·4	3·7	13,150	13,750	14,170
2·27	18	336	939	1345	0·3	2·9	17,550	18,150	18,535
2	16·25	697	1302	1708	0·2	2	26,820	27,416	27,800
1·81	15	1004	1609	2014	0·15	1·5	36,650	37,247	31,899
1·57	13	1627	2232	2637	0·1	1	56,525	57,120	57,500
1·32	11	2474	3076	3484					

Heat C_a required in *boiling-columns* to separate 100 kg. water from ammonia-water mixtures of 4—0·1% wt. (or, heat needed, per 100 kg. of exhausted liquor, to raise the ammonia-content of the vapour from 0·01% at the bottom up to 30% at the top). Calculated from the equation :

$$C_a = \frac{(w - w_e)(\alpha + f_d\beta)}{f - f_d}$$

Ammonia-content of liquid. wt. %	For 100 kg. spent liquor C_a kg. cal.	Ammonia-content of liquid. wt. %	For 100 kg. spent liquor C_a kg. cal.	Ammonia-content of liquid. wt. %	For 100 kg. spent liquor C_a kg. cal.
4	7160	1·81	6900	0·6	6580
3·52	7080	1·57	6900	0·4	6400
3	7050	1·32	6900	0·3	6130
2·79	7010	1·2	6880	0·2	5960
2·5	7000	1	6880	0·15	5960
2·27	7000	0·8	6710	0·1	5960
2	7000				

TABLE 53

Ammonia and Water

Water-content of liquid and vapour on each plate in *rectifying columns* when 20% (and 30%) ammonia vapour is produced with a reflux-heat expenditure C_R ranging from 3,500 to 20,000 kg. cal. (10,000—50,000 kg. cal.) for 10 kg. ammonia recovered.

No. of plate from top	Reflux heat C_R for 10 kg. ammonia (20%)									
	3500 kg. cal.		5000 kg. cal.		10,000 kg. cal.		15,000 kg. cal.		20,000 kg. cal.	
	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %
	2·5	20	2·5	20	2·5	20	2·5	20	2·5	20
1	2·26	18	2·3	17·25	1·85	15·25	1·6	13·7	1·44	12
2	2·26	18	2·2	16·8	1·81	15	1·6	13·5	1·44	12
	Reflux heat C_R for 10 kg. ammonia (30%)									
	10,000 kg.cal.		15,000 kg. cal.		20,000 kg. cal.		25,000 kg. cal.		50,000 kg. cal.	
	4	30	4	30	4	30	4	30	4	30
1	2·91	23	2·26	18·1	2	16·2	1·8	14·74	1·1	10·84
2	2·55	20·3	2·22	17·3	1·81	15·15	1·64	13·55	1·05	8·24
3	2·5	20	2·2	17	1·81	15·01	1·62	13·48		

TABLE 54

Ammonia and Water

Ammonia-content of liquid and vapour on each plate of *boiling-columns* when the heat-expenditure C_a ranges from 8,000 to 15,000 kg. cal. for 100 kg. exhausted liquor.

No. of plates from base	Heat expenditure for 100 kg. spent liquor							
	8000 kg. cal.		10,000 kg. cal.		11,000 kg. cal.		15,000 kg. cal.	
	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %
25	1·626	13·51	—	—	—	—	—	—
24	1·579	13·15	—	—	—	—	—	—
23	1·408	11·69	—	—	—	—	—	—
22	1·250	10·41	—	—	—	—	—	—
21	1·101	9·345	—	—	—	—	—	—
20	0·9615	8·264	5·26	38·6	—	—	—	—
19	0·8264	7·246	3·953	29·76	—	—	—	—
18	0·7142	6·25	2·932	23·04	—	—	—	—
17	0·5988	5·405	2·197	17·51	—	—	—	—
16	0·5000	4·545	1·626	13·33	—	—	—	—
15	0·3937	3·846	1·191	10	3·2	25	—	—
14	0·2881	2·809	0·8620	7·407	2·04	16·66	29·2	93
13	0·2262	2·217	0·5988	5·405	1·39	11·50	21·2	90·9
12	0·1748	1·721	0·4081	3·773	0·935	8	11·4	72·5
11	0·1321	1·305	0·2659	2·559	0·581	5·26	5·06	37·7
10	0·1128	1·117	0·1712	1·686	0·343	3·333	2·75	21·5
9	0·0877	0·862	0·1102	1·091	0·238	2·33	1·48	12
8	0·0705	0·6993	0·0709	0·704	0·141	1·39	0·74	6·45
7	0·05586	0·5555	0·0452	0·450	0·0787	0·7812	0·39	3·30
6	0·04366	0·4347	0·0289	0·288	0·04629	0·4608	0·16	1·62
5	0·0348	0·347	0·0185	0·1848	0·02717	0·2710	0·075	0·75
4	0·0279	0·2785	0·0118	0·1183	0·01605	0·1603	0·045	0·44
3	0·0217	0·2169	0·0075	0·0763	0·0095	0·0953	0·024	0·21
2	0·01615	0·1613	0·0048	0·0487	0·0056	0·0562	0·010	0·10
1	0·0128	0·1278	0·003	0·031	0·003	0·033	0·005	0·045
	0·012	0·10	0·002	0·02	0·002	0·020	0·002	0·02

TABLE 55

Ammonia and Water

Heat-consumption and ammonia-content on plate M (boiling-column) producing from 100 kg. liquor with 1·5—3% ammonia an aqueous ndensate containing 20, 25, 30%.

Ammonia-content of liquid wt. %	Product:	20 %		25 %		30 %	
	Boiling-temperature:	56°		40°		28° C.	
	Preheating-temperature:	56°	46°	40°	30°	28°	20° C.
1·5	Vapour of product: kg. cal.: C_e	3,680	3,680	2,873	2,873	2,303	2,303
	Heating on plate M: kg. cal.: C_n	0	2,625	0	3,330	0	4,200
	Ammonia-content of liquid: wt. %	13	20	13	25	13	30
	Ammonia-content of vapour: wt. %	1·5	2·5	1·5	3·2	1·5	4·0
	Total heat for 100 kg. C_a	6,300	6,300	6,405	6,405	6,510	6,510
	Reflux heat liquid C_R	2,620	0	4,032	0	4,210	0
	Reflux heat for 100 kg. Amm. C_R	17,464	0	26,877	0	28,120	0
	Total heat for 100 kg. W. C_a	6,800	6,804	6,750	6,750	6,850	6,850
2·0	Vapour of product: kg. cal.: C_e	4,900	4,910	3,830	3,830	3,070	3,070
	Heating on plate M: kg. cal.: C_n	0	1,400	0	2,590	0	3,500
	Ammonia-content of liquid: wt. %	2	2·5	2	3·2	2	4
	Ammonia-content of vapour: wt. %	16·25	20	16·25	25	16·25	30
	Total heat for 100 kg. C_a	6,300	6,300	6,440	6,440	6,580	6,580
	Reflux heat liquid C_R	1,390	0	2,610	0	3,510	0
	Reflux heat for 100 kg. Amm. C_R	6,950	0	13,050	0	17,550	0
	Total heat for 100 kg. W. C_a	6,950	6,950	6,980	6,980	7,080	7,080
2·5	Vapour of product: kg. cal.: C_e	6,137	6,137	4,788	4,788	3,838	3,838
	Heating on plate M: kg. cal.: C_n	0	0	0	1,590	0	2,625
	Ammonia-content of liquid: wt. %	2·5	2·5	2·5	3·2	2·5	4
	Ammonia-content of vapour: wt %	20	20	20	25	20	30
	Total heat for 100 kg. C_a	6,135	6,135	6,300	6,300	6,475	6,475
	Reflux heat liquid C_R	0	0	1,512	0	2,637	0
	Reflux heat for 100 kg. Amm. C_R	0	0	6,048	0	10,588	0
	Total heat for 100 kg. W. C_a	7,055	7,055	6,900	6,900	7,000	7,000
3·0	Vapour of product: kg. cal.: C_e	7,360	7,360	5,745	5,745	4,605	4,605
	Heating on plate M: kg. cal.: C_n	0	0	0	437	0	1,750
	Ammonia-content of liquid: wt. %	3	3	3	3·2	3	4
	Ammonia-content of vapour: wt. %	23·5	23·5	23·5	25	23·5	30
	Total heat for 100 kg. C_a	6,090	6,090	6,160	6,160	6,300	6,300
	Reflux heat liquid C_R	0	0	415	0	1,645	0
	Reflux heat for 100 kg. Amm. C_R	0	0	1,350	0	5,485	0
	Total heat for 100 kg. W. C_a	713 C	7,130	7,140	7,140	6,900	6,900

TABLE 56

Weight and volume of 1 kg. of air, oxygen, and nitrogen under atmospheric pressure (760 mm.) and at the temperatures given in Column 1.

Temps.		Weight (kg.) of 1 cb. metre of gas			Volume (litres) of 1 kg. of gas		
Abs.	° C.	Air	Oxygen	Nitrogen	Air	Oxygen	Nitrogen
95	−178	3·71	4·10	3·598	269·5	243·9	278·0
94	−179	3·75	4·14	3·637	266·5	241·5	275·0
93	−180	3·78	4·17	3·666	264·5	239·8	272·8
92	−181	3·82	4·22	3·705	261·8	236·9	270·0
91	−182	3·85	4·25	3·734	259·7	235·3	267·8
90	−183	3·91	4·32 [1]	3·792	255·7	231·4	263·8
89	−184	3·95	—	3·831	253·2	—	261·1
88	−185	3·99	—	3·870	250·6	—	258·3
87	−186	4·04	—	3·918	247·5	—	255·3
86	−187	4·086	—	3·960	245·2	—	252·5
85	−188	4·14	—	4·015	241·5	—	249·0
84	−189	4·18	—	4·054	239·2	—	246·6
83	−190	4·24	—	4·112	235·8	—	243·1
82	−191	4·29	—	4·161	233·1	—	240·3
81	−192	4·35	—	4·219	229·9	—	237·0
80	−193	4·40	—	4·275	227·2	—	233·9
79	−194	—	—	4·325	—	—	231·1
78	−195	—	—	4·379	—	—	228·5
77	−196	—	—	4·437	—	—	225·3

[1] U. Behn (*Ann. Physik*, 1900, **1**, 270) derives the specific volume s of a mixture of 93 % oxygen and 7 % nitrogen at −183° C. from the equation:

$$s = \frac{Jr}{T\frac{dP}{dT}} = \frac{422 \times 50{\cdot}8 \times 10^5}{90 \times 66{,}700} = 357$$

where
J = mechanical equivalent of heat
r = latent heat of vaporisation
T = absolute temperature
$\frac{dP}{dT}$ = temperature coefficient.

Hence the density is $\frac{1}{357} = 0{\cdot}0028$,
i.e., 1 cb. m. of the mixture weighs 2·8 kg.
[According to E. Mathias and H. K. Onnes the density of saturated oxygen vapour at − 182° C. is 0·0051.]

TABLE 57 (Charts XV, XVI)

Nitrogen and Oxygen (Air)

Nitrogen-content of liquid nitrogen-oxygen mixtures and of the vapours arising therefrom. Ratios of liquids $\frac{o}{n} = f$, and of vapours $\frac{o_d}{n_d} = f_d$. Values of $\frac{\alpha + f\beta}{f - f_d}$ and $\frac{\alpha + f_d\beta}{f - f_d}$.

Data by Baly* (amplified by the author)

Temp. abs.	Nitrogen in liquid n %	f	Nitrogen in vapour n_d %	f_d	$\frac{\alpha + f\beta}{f - f_d}$	$\frac{\alpha + f_d\beta}{f - f_d}$	Latent heat $\frac{\alpha}{\beta}$
77·54	*100		100				47·64
(−195·46)	99	0·0101	99·96	0·0034	7160	7100	53·51
	98	0·0204	99·33	0·0069	3575	3517	
	97	0·0309	99	0·0101	2358	2308	
	96	0·0417	98·75	0·0127	1712	1656	
	95	0·0525	98·5	0·0152	1348	1294	
	94	0·0638	98·25	0·0178	1105	1052	
	93	0·0752	98	0·0204	939	885	
	92	0·0869	97·83	0·0223	807	750	
78	*91·9	0·088	97·82	0·0223	793	740	47·51
(−195)	91	0·099	97·44	0·0263	721	668	53·41
	90	0·111	97·1	0·0298	652	602	
	89·5	0·117	97	0·0309	621	568	
	89	0·123	96·86	0·0325	592	540	
	88	0·136	96·57	0·0355	543·2	490·6	
	87	0·149	96·29	0·0385	500·4	447·0	
	86	0·162	96	0·0417	466·4	413·0	
	85	0·176	95·68	0·0451	433·5	380·0	
78·5	*84·75	0·180	95·62	0·0458	424·9	371·5	47·37
(−194·5)	84	0·191	95·33	0·0490	404·0	350·7	53·30
	83	0·205	95	0·0525	379·5	326·8	
	82	0·219	94·6	0·0571	364·5	311·3	
	81	0·234	94·2	0·0615	346·2	292·9	
	80·5	0·242	94	0·0638	337·7	284·3	
	80	0·250	93·8	0·0661	329·0	275·8	
	79	0·266	93·4	0·0706	314·3	261·1	
79	*78·4	0·275	93·2	0·0739	307·0	253·9	47·24
(−194)	78	0·282	93	0·075	300·5	246·8	53·20
	77	0·299	92·6	0·080	288·2	235·5	
	76	0·316	92·2	0·085	276·0	222·8	
	75·5	0·324	92	0·087	270·0	217·1	
	75	0·333	91·8	0·089	266·1	213·0	
	74	0·352	91·4	0·094	255·0	202·1	
	73	0·370	91	0·099	246·2	193·1	

Temp. abs.	Nitrogen in liquid n %	f	Nitrogen in vapour n_d %	f_d	$\frac{\alpha + f\beta}{f - f_d}$	$\frac{\alpha + f_d\beta}{f - f_d}$	Latent heat $\frac{\alpha}{\beta}$
79·5	*72·33	0·382	90·67	0·103	241·8	188·6	47·10
(−193·5)	72	0·389	90·5	0·105	237·7	184·8	53·09
	71	0·409	90	0·111	231·0	177·2	
	70	0·429	89·5	0·117	223·7	170·5	
	69	0·449	89	0·123	217·0	163·7	
	68	0·470	88·15	0·134	214·0	160·6	
	67	0·489	88·15	0·134	205·3	152·3	
80	*66·65	0·501	88	0·136	201·7	148·4	46·97
(−193)	66	0·515	87·6	0·142	198·3	145·5	52·99
	65	0·538	87·1	0·148	192·7	139·8	
	64	0·563	86·5	0·156	188·0	134·8	
	63	0·587	86·1	0·161	182·9	130·0	
	62	0·613	85·45	0·170	179·0	126·1	
80·5	*61·46	0·627	85·22	0·174	176·8	123·7	46·83
(−192·5)	61·2	0·634	85	0·176	175·0	122·0	52·88
	61	0·639	84·9	0·178	174·4	121·7	
	60	0·666	84·32	0·186	170·4	117·5	
	59·4	0·683	84	0·191	168·0	115·2	
	59	0·695	83·74	0·194	166·6	113·8	
	58	0·724	83·16	0·202	163·0	110·5	
	57·6	0·736	83	0·205	160·8	108·1	
	57	0·754	82·65	0·210	156·2	104·6	
81	*56·62	0·766	82·34	0·215	157·6	104·9	46·70
(−192)	56	0·785	82	0·219	154·8	102·2	52·78
	55	0·818	81·33	0·230	151·2	99·6	
	54·4	0·837	81	0·234	150·3	97·7	
	54	0·851	80·66	0·239	149·0	96·3	
	53	0·887	80	0·250	146·3	93·7	
81·5	*52	0·923	79·33	0·261	143·3	90·8	46·56
(−191·5)	51·5	0·941	79	0·266	141·9	89·3	52·67
	51	0·961	78·66	0·271	139·6	87·4	
	50	1	78	0·282	138·4	84·5	
	49	1·041	77·25	0·294	135·3	82·1	
	48·7	1·053	77	0·299	134·0	81·9	
	48	1·082	76·5	0·307	132·8	80·65	
82	*47·83	1·091	76·40	0·309	131·0	79·4	46·43
(−191)	47·3	1·114	76	0·316	130·2	76·1	52·57
	47	1·128	75·75	0·320	130·2	78·04	
	46	1·174	75	0·330	127·0	75·0	
	45	1·222	74·16	0·348	126·5	73·6	
	44·8	1·232	74	0·352	125·4	73·2	
82·5	*44·06	1·269	73·27	0·365	124·0	72·0	46·30
(−190·5)	44	1·273	73·20	0·366	124·3	71·8	52·46

Temp. abs.	Nitrogen in liquid n %	f	Nitrogen in vapour n_d %	f_d	$\frac{\alpha + f\beta}{f - f_d}$	$\frac{\alpha + f_d\beta}{f - f_d}$	Latent heat $\frac{\alpha}{\beta}$
	43·7	1·288	73	0·370	123·0	71·39	
	43	1·326	72·65	0·376	120·7	69·0	
	42·5	1·352	72·1	0·387	120·6	68·9	
	42	1·380	71·6	0·396	120·4	68·2	
	41·4	1·415	71	0·409	120·1	67·45	
	41	1·439	70·6	0·416	118·4	66·37	
83	*40·45	1·471	70·05	0·427	118·0	65·7	46·16
(190)	40	1·500	69·6	0·437	116·8	64·85	52·36
	39·4	1·538	69	0·449	115·9	63·79	
	39	1·564	68·6	0·458	115·7	63·5	
	38·4	1·604	68	0·470	114·2	62·12	
	38	1·630	67·65	0·478	113·8	61·69	
	37·4	1·673	67	0·489	113·3	60·57	
83·5	*37·07	1·689	66·65	0·500	112·5	60·56	46·03
(189·5)	37	1·703	66·6	0·501	111·2	59·76	52·25
	36·3	1·754	66	0·515	110·6	58·74	
	36	1·778	65·7	0·522	110·0	58·1	
	35·35	1·833	65	0·538	108·9	57·12	
	35	1·857	64·6	0·548	108·8	56·84	
	34·5	1·898	64	0·563	108·0	56·32	
	34	1·941	63·4	0·577	107·1	55·44	
84	*33·8	1·958	63·15	0·584	107·4	55·54	45·89
(189)	33·6	1·976	63	0·587	106·8	54·91	52·15
	33	2·033	62	0·613	106·3	54·63	
	32	2·124	61	0·639	106·0	53·17	
	31	2·225	60	0·666	103·3	51·61	
84·5	*30·69	2·259	59·55	0·679	102·5	50·94	45·76
(188·5)	30·34	2·299	59	0·693	102·7	50·80	52·05
	30	2·333	58·57	0·708	102·4	50·57	
	29·56	2·381	58	0·724	102·0	50·25	
	29	2·449	57·26	0·747	101·5	49·54	
	28·8	2·472	57	0·754	101·0	49·32	
	28	2·570	56	0·785	100·5	48·55	
85	*27·73	2·609	55·75	0·794	99·9	47·91	45·62
(—188)	27·32	2·662	55	0·818	99·3	47·72	51·95
	27	2·704	54·58	0·832	98·9	47·4	
	26·57	2·765	54	0·851	98·1	46·77	
	26	2·847	53·26	0·877	98·0	46·17	
	25·03	2·998	52	0·923	96·4	45·01	
	25	3	51·96	0·924	96·4	45·01	
85·5	*24·9	3·016	51·83	0·930	96·4	44·88	45·48
(—187·5)	24·2	3·132	51	0·961	95·4	43·8	51·84
	24	3·167	50·6	0·976	94·9	43·7	

Temps. abs.	Nitrogen in liquid n %	f	Nitrogen in vapour n_d %	f_d	$\frac{\alpha + f\beta}{f - f_d}$	$\frac{\alpha + f_d\beta}{f - f_d}$	Latent heat $\frac{\alpha}{\beta}$
	23·6	3·237	50	1	94·7	43·35	
	23	3·348	49·2	1·033	94·1	42·6	
	22·9	3·366	49	1·042	94·1	42·6	
	22·26	3·501	48	1·082	93·5	41·8	
86	*22	3·542	47·85	1·105	93·7	42·0	45·35
(187)	21·6	3·629	47	1·128	92·8	41·2	51·74
	21	3·762	46	1·174	92·4	40·8	
	20·9	3·784	45·7	1·188	92·6	41·1	
	20·35	3·922	45	1·222	91·3	40·0	
	20	4	44·3	1·257	91·7	40·1	
	19·72	4·075	44	1·273	91·2	39·6	
86·5	*19·56	4·118	43·7	1·288	90·9	39·5	45·21
(−186·5)	19	4·261	43	1·326	90·0	38·6	51·64
	18·4	4·434	42	1·380	89·8	37·9	
	18	4·550	41·2	1·427	89·5	37·9	
	17·8	4·617	41	1·439	89·2	37·6	
	17·3	4·780	40	1·500	89·0	37·2	
87	*17·05	4·861	39·47	1·533	88·8	37·0	45·08
(−186)	17	4·882	39·4	1·538	88·7	37·0	51·53
	16·8	4·952	39	1·564	88·5	36·8	
	16·2	5·172	38	1·630	87·7	36·3	
	16	5·250	37·6	1·659	87·6	36·4	
	15·7	5·369	37	1·703	87·6	36·3	
	15·2	5·578	36	1·778	87·2	35·7	
	15	5·660	35·8	1·793	86·8	35·3	
	14·7	5·802	35·2	1·840	86·7	35·1	
87·5	*14·69	5·826	35·15	1·845	86·3	35·0	44·94
(−185·5)	14·2	6·042	34·10	1·932	86·1	34·9	51·42
	14	6·143	33·60	1·976	86·1	35·0	
	13·7	6·299	33	2·033	86·1	34·8	
	13·2	6·575	32	2·115	85·5	34·2	
	13	6·692	31·6	2·154	85·3	34·1	
	12·7	6·872	31	2·226	85·3	33·9	
88	*12·4	7·064	30·42	2·289	85·2	33·9	44·81
(−185)	12·27	7·175	30	2·333	85·2	33·9	51·32
	12	7·333	29·4	2·401	85·2	33·9	
	11·82	7·472	29	2·449	84·9	33·6	
	11·35	7·801	28	2·571	84·8	33·8	
	11	8·091	27·93	2·580	84·7	33·6	
	10·9	8·169	27	2·704	84·6	33·4	
	10·45	8·570	26·18	2·820	84·0	32·8	
	10·33	8·653	26	2·847	83·9	32·6	

Temp. abs.	Nitrogen in liquid n %	f	Nitrogen in vapour n_d %	f_d	$\frac{\alpha + f\beta}{f - f_d}$	$\frac{\alpha + f_d\beta}{f - f_d}$	Latent heat $\frac{\alpha}{\beta}$
88·5	*10·18	8·847	25·63	2·900	83·6	32·4	44·67
(−184·5)	10	9	25	3	84·1	32·9	51·21
	9·55	9·470	24	3·167	83·7	32·6	
	9·1	9·981	23	3·348	83·7	32·4	
	9	10·111	22·63	3·423	83·7	32·7	
	8·65	10·562	22	3·542	83·0	32·0	
	8·21	11·180	21	3·762	82·8	31·8	
89	*8·02	11·470	20·55	3·865	83·0	31·9	44·54
(184)	8	11·5	20·48	3·899	82·6	31·8	51·11
	7·75	11·9	20	4	82·4	31·2	
	7·35	12·6	19	4·266	82·4	31·4	
	7·03	13·22	18	4·550	82·4	31·2	
	7	13·29	17·89	4·5858	82·5	31·7	
	6·95	13·32	17·8	4·617	83·1	31·9	
	6·65	14·03	17	4·882	82·6	30·5	
	6·5	14·38	16·86	4·930	82·2	30·1	
	6·3	14·87	16	5·256	83·3	30·7	
	6·1	15·39	15·9	5·289	82·07	31·08	
	6	15·78	15·62	5·467	82·35	31·3	
89·5	*5·91	15·91	15·45	5·470	81·9	30·9	44·40
(−183·5)	5·7	16·54	15	5·660	81·50	30·6	51·00
	5·3	17·66	14	6·143	81·86	31	
	5	19	13·15	6·601	81·6	30·7	
	4·9	19·4	13	6·692	81·8	30·3	
	4·5	21·21	12	7·333	81·2	30·2	
	4·1	23·39	11	8·091	80·6	30·0	
	4	24·90	10·52	8·509	82·0	30·8	
90	*3·85	25·90	10·2	8·803	81·3	30·6	44·27
(−183)	3·77	25·52	10	9	81·2	33·1	50·90
	3·47	27·83	9	10·11	82·7	30·5	
	3·03	32	8	11·5	81·4	30·6	
	3	32·33	7·89	11·669	81·6	30·8	
	2·63	37·02	7	13·286	81·0	30·3	
	2·26	43·24	6	15·78	81·5	30·7	
	2	49	5·26	18·01	81·8	31·0	
	1·9	51·62	5	19	81·8	31·0	
90·5	*1·84	53·34	4·9	19·4	81·1	30·3	44·14
(−182·5)	1·5	65·58	4	24	80·8	30·2	50·80
	1·1	89·99	3	32·333	79·7	29·0	
	1	99	2·63	37·02	82·2	30·9	
	0·7	141·86	2	49	78·1	27·3	
90·69	*0·3	332·3	1	99	72·5	21·66	44·01
(−182·31)							50·70

TABLE 58 (CHART XIV)

Nitrogen and Oxygen (Air)

Reflux heat C_R required in *rectifying columns* to produce 1 kg. nitrogen as vapour of 95, 98, 99·5% wt. from liquid mixtures of nitrogen and oxygen containing from 80% to 10% nitrogen.

Nitrogen-content.		Heat needed to produce 1 kg. nitrogen as product of			Nitrogen-content.		Heat needed to produce 1 kg. nitrogen as product of		
Liq. wt. %	Vap. wt. %	95% C_R kg. cal.	98% C_R kg. cal.	99·5% C_R kg. cal.	Liq. wt. %	Vap. wt. %	95% C_R kg. cal.	98% C_R kg. cal.	99·5% C_R kg. cal.
80	93·8	4·6	15·0	20·0	14·69	35·15	154·2	157·0	158·7
77	92·6	7·0	15·6	21·7	13·7	33	170·4	173·0	174·7
75	91·8	9·8	16·4	22·4	12·27	30	194·2	196·8	198·4
70	89·5	14·6	21·6	25·0	11·35	28	213·6	216·2	217·9
65	87·1	18·5	24·5	27·7	10·9	27	223·3	226·7	228·4
60	84·3	22·6	27·8	30·6	10·33	26	230·3	237·3	238·2
55	81·3	26·6	31·5	33·8	10	25	246·9	249·4	250·2
50	78	31·6	36·1	38·2	9·55	24	—	—	—
46	75	35·2	39·3	42·1	9·1	23	—	—	—
40·4	70·05	44·2	48·0	49·7	8·65	22	—	—	—
35·35	65	52·9	56·4	58·0	8·21	21	—	—	—
31	60	63·2	66·5	68·0	8	20·48	—	—	—
27·32	55	76·0	79·2	80·8	5·7	15	—	—	—
23·6	50	89·7	92·8	94·2	3·77	10	—	—	—
20·35	45	106·8	109·5	111·2	3	7·89	—	—	—
17·3	40	128·3	131·1	132·5	1·9	5	—	—	—

Heat C_a required in *boiling-columns* to separate at the base 100 kg. of oxygen containing from 80% to 1·9% wt. (or, heat required, per 100 kg. oxygen, to raise the nitrogen-content of the vapour from 0·01% at the base of the column to 93·8% at the top.

Nitrogen in liquid %	Heat for 100 kg. oxygen C_a kg. cal.	Nitrogen in liquid %	Heat for 100 kg. oxygen C_a kg. cal.	Nitrogen in liquid %	Heat for 100 kg. oxygen C_a kg. cal.	Nitrogen in liquid %	Heat for 100 kg. oxygen C_a kg. cal.
80	27,580	46	7,500	14·69	3,500	9·1	3,240
77	23,550	40·4	6,570	13·7	3,480	8·65	3,200
75	21,300	35·35	5,712	12·27	3,390	8·21	3,180
70	17,050	31	5,161	11·35	3,380	8	3,120
65	13,980	27·32	4,772	10·9	3,340	5·7	3,061
60	11,750	23·6	4,335	10·33	3,260	3·77	3,050
55	9,960	20·35	4,000	10	3,290	3	3,080
50	8,450	17·3	3,720	9·55	3,260	1·9	3,100

TABLE 59

Nitrogen and Oxygen (Air)

Nitrogen-content of liquid and vapour on each plate in *rectifying columns* when vapour containing 99·5% nitrogen (0·5% oxygen) is produced with heat-expenditure C_R ranging from 800 to 2,500 kg. cal. for every 10 kg. nitrogen.

No. of plate from top.	Reflux heat C_R for 10 kg. nitrogen.									
	800 kg. cal.		1,000 kg. cal.		1,500 kg. cal.		2,000 kg. cal.		2,500 kg. cal.	
	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %
	98·5	99·5	98·5	99·5	98·5	99·3	98·5	99·5	98·5	99·5
1	97·6	99·2	97	99	96·7	98·9	96·5	98·88	96·2	98·8
2	94	98·28	91·9	97·82	91	97·5	90	97·12	88·5	96·77
3	86·5	96·15	81·5	94·44	78·4	93·17	75	91·84	72·4	90·75
4	74·1	91·45	66	87·62	58·8	83·61	52·5	79·84	47·83	76·44
5	54	80·61	48·6	76·95	39·2	68·77	32·83	61·83	28·4	56·34
6	42	71·4	36	65·57	26·6	54·02	21·06	46·22	17·5	40·45
7	34·7	64·59	29	57·21	20·2	44·92	15·7	36·93	12·85	21·278
8	30·7	59·68	25·2	52·48	17·1	39·63	13·5	32·63	10·95	27·53
9	28·8	57	23·65	50·07	16·1	37·81	12·5	30·76	10·25	25·79

Reflux heat in rectifying columns for 10 kg. nitrogen as vapour of 95% wt. (5% oxygen).

	50 kg. cal.		80 kg. cal.		140 kg. cal.		180 kg. cal.		220 kg. cal.	
	83	95	83	95	83	95	83	95	83	95
1	80·25	93·9	78·9	93·4	76·6	92·4	75	91·7	73·7	91·4
2	79·7	93·7	77·6	92·8	73·3	91·1	70·5	89·8	68·5	88·65
3	79·65	93·65	77·2	92·65	71·75	90·4	68·7	88·7	65·2	87·15
4	79·5	93·6	77·1	92·6	71·15	90·1	68·5	88·2	63·1	86·18
5	79·3	93·6	77·0	92·6	70·9	89·9	66·8	88·1	62·1	85·5

TABLE 60

Nitrogen and Oxygen (Air)

Nitrogen-content of liquid and vapour on each plate of *boiling-columns* when the heat-expenditure C_a ranges from 25,000 to 85,000 kg. cal. for 100 kg. oxygen run off from the base.

No. of plate from base.	Heat-expenditure C_a for 100 kg. oxygen.									
	25,000 kg. cal.		35,000 kg. cal.		50,000 kg. cal.		70,000 kg. cal.		85,000 kg. cal.	
	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %
10	76·69	92·45	81·78	94·25	87·64	96·45	91·12	97·5	92·19	97·9
9	73·94	91·3	80·57	94·0	86·08	96·0	90·0	97·15	91·55	97·6
8	68·32	88·4	75·27	91·9	80·98	94·2	86·7	96·2	88·59	96·7
7	55·09	81·33	62·10	85·5	70·805	89·40	77·16	92·8	78·89	93·38
6	36·08	65·7	41·16	70·7	49·86	77·85	57·18	82·75	58·73	83·6
5	19·17	43·25	23·33	49·6	27·05	54·65	31·76	60·75	32·96	61·96
4	9·21	23·0	10·770	26·6	12·13	29·7	14·15	33·975	14·53	34·8
3	4·18	11·2	4·646	12·3	5·284	13·25	5·75	15·1	5·89	15·4
2	1·891	4·95	2·039	5·35	2·235	5·90	2·32	6·20	2·353	6·300
1	0·83	2·28	0·854	2·32	0·908	2·436	0·9327	4·88	0·944	2·514
	0·3	1	0·3	1	0·3	1	0·3	1	0·3	1

TABLE 61 (Chart XVI)

$\alpha = 46$
$\beta = 40$

Nitrogen and Argon

Nitrogen-content of liquid mixtures of nitrogen and argon and of the vapours arising therefrom. Ratios of liquids $\frac{a}{n} = f$, and of vapours $\frac{a_d}{n_d} = f_d$. Values of $\frac{\alpha + f\beta}{f - f_d}$ and $\frac{\alpha + f_d\beta}{f - f_d}$.

The vapour-composition curve of Holst and Hamburger (*Z. physik. Chem.*, 1916, **91**, 513) has been used for calculating the percentage weights here given.

Abs. temp. T	Nitrogen in liquid n %	f	Nitrogen in vapour n %	f_d	$\frac{\alpha + f\beta}{f - f_d}$	$\frac{\alpha + f_d\beta}{f - f_d}$
77·28	100	0	100	0	—	—
	99	0·0101	99·45	0·0055	10,060	10,020
	98·7	0·0132	99·285	0·0072	7,754	7,712
	98	0·0204	98·90	0·0111	5,031	5,005
	97	0·0309	98·35	0·0168	3,347	3,309
	96	0·0417	97·80	0·0225	2,361	2,316
	95	0·0526	97·25	0·0280	1,953	1,910
	94	0·0638	96·70	0·0341	1,631	1,593
	93	0·0753	96·15	0·0400	1,386	1,347
	92	0·0870	95·6	0·0460	1,206	1,169
	91	0·0989	95·05	0·0520	1,041	1,003
	90	0·1111	**94·5**	0·0582	953	913
	89	0·1230	94	0·0638	857	819
	88	0·1364	93·5	0·0695	770	730
	87	0·1494	93	0·0753	702	662
	86	0·1628	92·5	0·0811	637	603
	85	0·1765	92	0·0870	593	554
	84	0·1905	91·5	0·0929	549	507
	83	0·2048	91	0·0989	511	471
	82	0·2198	90·5	0·1050	475	435
	81	0·2346	90	0·1111	448	408
	80	0·2500	**89·5**	0·1173	422	382
	79	0·2658	88·9	0·1249	401	362
	78	0·2820	88·40	0·1312	379	339
78·3	77	0·2987	87·85	0·1380	360	320
	76	0·3158	87·30	0·1455	345	305

Abs. temp. T	Nitrogen in liquid n %	f	Nitrogen in vapour n %	f_d	$\frac{\alpha + f\beta}{f - f_d}$	$\frac{\alpha + f_d\beta}{f - f_d}$
	75	0·3333	86·75	0·1527	328	289
	74	0·3513	86·20	0·1601	316	276
	73	0·3696	85·65	0·1675	300·8	261
	72	0·3889	84·90	0·1751	288	248
	71	0·4085	84·55	0·1827	276	236
	70	0·4286	**84**	0·1905	265	225
	69	0·4493	83·3	0·2005	257	217
	68	0·4706	82·6	0·2107	249·2	209
	67	0·4925	81·9	0·2210	241·6	201·6
80·66	66	0·5152	81·2	0·2319	235	195
	65	0·5385	80·5	0·2422	228	188
	64	0·5625	79·8	0·2531	221	182
	63	0·5873	79·1	0·2642	216	176
	62	0·6129	78·4	0·2755	209	169
	61	0·6393	77·7	0·2870	204	163
	60	0·6667	**77**	0·2987	197	158
	59	0·6949	76·36	0·3098	192	152
	58	0·7241	75·72	0·3210	186	146
79·41	57	0·7544	75·08	0·3320	181	141
	56	0·7857	74·44	0·3440	175	135
	55	0·8189	73·8	0·3550	170	130
	54	0·8519	73·14	0·3670	165	125
	53	0·8858	72·48	0·3799	161	121
	52	0·9231	71·82	0·3928	157	117
	51	0·9608	71·16	0·4055	152	112
	50	1·0000	**70·5**	0·4225	149	109
	49	1·0408	69·67	0·4358	145	105
	48	1·0821	68·84	0·4530	142	102
	47	1·1277	68·01	0·4706	138	98·5
	46	1·1739	67·18	0·4880	135	96
	45	1·2222	66·35	0·5070	133	93
82·97	44	1·2727	65·48	0·5272	130	90
	43	1·3256	64·61	0·5480	127	87·5
	42	1·3810	63·74	0·5686	124	85
	41	1·4390	62·87	0·5900	121	82
	40	1·5000	**62**	0·6129	119	80
	39	1·5641	61·13	0·6360	116	77
	38	1·6316	60·26	0·6597	114	74·5
	37	1·7027	59·39	0·6830	112	72
	36	1·7778	58·52	0·7090	109	70
	35	1·8571	57·65	0·7346	107	67·3
	34	1·9412	56·78	0·7610	105	65
	33	2·0303	55·91	0·7889	103	63
	32	2·1250	55·04	0·8182	100	61
	31	2·2258	54·17	0·8455	98·1	58
	30	2·3333	**53·3**	0·8762	95·4	55·7

Abs. temp. T	Nitrogen in liquid n %	f	Nitrogen in vapour n %	f_d	$\frac{\alpha + f\beta}{f - f_d}$	$\frac{\alpha + f_d\beta}{f - f_d}$
	29	2·4483	52·145	0·9177	93·8	54·1
	28	2·5714	51·083	0·9608	92·3	52·5
	27	2·7037	50·12	0·9959	90·5	50·5
	26	2·8462	49·06	1·0388	88·6	48·6
	25	3·0000	48	1·0833	86·6	46·6
82·40	24	3·1667	46·8	1·1368	85	45
	23	3·3478	45·6	1·1930	83·5	43·5
	22	3·5455	44·4	1·2525	81·4	42
	21	3·7619	43·2	1·3148	80	40·2
	20	4·0000	42	1·3810	78·5	38·5
	19	4·2632	40·4	1·4753	77·7	37·6
85·46	18	4·5555	38·8	1·5773	76·6	36·6
	17	4·8824	37·2	1·6882	75·5	35·4
	16	5·2500	35·6	1·8090	74·2	34·2
	15	5·6670	34	1·9412	73	33·1
	14	6·1429	32·3	2·0960	72·1	32
	13	6·6923	30·6	2·2698	70·8	30·8
	12	7·3333	28·9	2·4602	69·5	29·5
	11	8·0909	27·2	2·6765	67·8	28·1
	10	9·0000	25·5	2·9215	67·3	27·5
	9	10·1111	22·96	3·5768	67	26·8
	8	11·5000	20·42	3·9900	66·9	26·7
85·25	7	13·2857	17·88	4·6210	66·8	26·6
	6	15·6667	15·34	5·5130	66·7	26·5
	5	19·0000	12·8	6·8125	66·6	26·4
	4	24·0000	10·3	8·7087	66·5	26·3
	3	32·332	7·5	12·333	66·4	26·2
	2	49·000	5	19·000	66·3	26·1
87·26	1	99·000	2·5	39·000	66	26
	0·5	199·000	1·25	79·000	66·64	26·65
	0·25	399·000	0·625	160·000	66·16	26·66
	0·10	999·000	0·25	399·000	66·8	26·7

TABLE 62

Nitrogen and Argon

Reflux heat C_R needed in *rectifying columns* to produce 1 kg. nitrogen as vapour of 90, 95, 99·5% wt. from liquid nitrogen-argon mixtures containing from 0·25% to 99% nitrogen.

Nitrogen-content.		Heat needed to produce 1 kg. nitrogen as product of			Nitrogen-content.		Heat needed to produce 1 kg. nitrogen as product of		
Liq. wt. %	Vap. wt. %	90% C_R kg.cal.	95% C_R kg.cal.	99·5% C_R kg.cal.	Liq. wt. %	Vap. wt. %	90% C_R kg. cal.	95% C_R kg. cal.	99·5% C_R kg. cal.
99	99·45	—	—	55·83	20	42	99	104·4	108·3
98·7	99·285	—	—	55·70	15	34	133·5	137	141
90	94·5	—	—	50·50	12	28·9	163	167	171
85	92	—	20·75	48·62	10	25·5	189	193	196
80	89·5	25·32	27·43	47·2	9	25·5	219	222	226
75	86·75	25·6	32·8	48·2	8	20·42	253	257	261
70	84	26·9	36·5	49	7	17·88	301	305	308
65	80·5	27·3	41	51·7	6	15·34	360	364	367
60	77	37	48·6	57·9	5	12·8	446	450	453
55	73·8	41·4	51·5	59·5	4	10·3	571	575	579
50	72·48	46·3	55·1	62·1	3	7·5	803	815	820
45	66·35	52·6	60·5	66·7	2	5	1,250	1,253	1,259
40	62	59·7	66·6	72·2	1	2·5	2,569	2,575	2,580
35	57·65	66·6	72·9	78	0·5	1·25	5,245	5,245	5,245
30	53·3	72·98	78·6	83·1	0·25	0·625	14,390	14,390	14,390
25	48	84·2	89·1	93					

Heat of vaporisation C_a needed in *boiling-columns* to separate 100 kg. argon from nitrogen-argon mixtures of 99—1% wt. nitrogen (or, heat needed to raise the nitrogen-content of vapour from 0·01% at the bottom to 99% at the top).

Nitrogen in liquid. wt. %	For 100 kg. argon. C_a kg. cal.	Nitrogen in liquid. wt. %	For 100 kg. argon. C_a kg. cal.	Nitrogen in liquid. wt. %	For 100 kg. argon. C_a kg. cal.
99	100,200	50	10,900	9	2,680
98·7	171,160	45	9,300	8	2,670
90	91,300	40	8,000	7	2,660
85	55,400	35	6,730	6	2,650
80	83,200	30	5,570	5	2,640
75	28,900	25	4,660	4	2,630
70	22,500	20	3,850	3	2,620
65	18,800	15	3,310	2	2,610
60	15,800	12	2,950	1	2,600
55	13,000	10	2,750		

TABLE 63

Nitrogen and Argon

Nitrogen-content of liquid and vapour on each plate in *rectifying columns* when 10 kg. nitrogen is produced with a reflux-heat expenditure C_R ranging from 5,000 to 100,000 kg. cal.

No. of plate from top.	Reflux-heat C_R for 10 kg. nitrogen.									
	5000 kg. cal.		12,500 kg. cal.		25,000 kg. cal.		50,000 kg. cal.		100,000 kg. cal.	
	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %
	Nitrogen of 95% wt. (5% argon)									
	91	95	91	95	91	95	91	95	91	95
1	83·4	91·35	83·5	91·35	83·3	91·4	83·2	91·45	83·5	91·5
2	71·4	84·6	71·3	84	71·2	83·6	71	83·4	71	84·6
3	54	73·2	52·9	72·2	51·9	71·6	51·7	71·4	51·5	71·4
4	34·7	57·4	31·7	54·6	29·5	52·8	29	52·1	28·8	51·9
5	21	43·1	15	34	13	30·7	12·5	29·6	12	29·1
6	11	27·2	6·9	17·4	5·6	14·5	5·2	13·2	4·95	12·5
7	6·9	17·5	4·7	10·5	3	7·3	2·55	6	2·2	5·3
8	6	13·9	3	7·1	1·9	4·5	1·39	3·3	1·05	2·6
9	5·7	13·1	2·5	6	1·33	3·2	0·9	2·15	0·6	1·45
	Nitrogen of 99·45% wt. (0·55% argon)									
	99	99·45	99	99·45	99	99·45	99	99·45	99	99·45
1	98·31	99·1	98·3	99·1	98·3	99	98·3	99	98·29	99
2	97	98·4	97	98·4	96·9	98·25	96·9	98·3	96·9	98·3
3	94·8	97·1	94·7	97	94·6	97	94·5	96·9	94·4	96·9
4	91·55	95·3	91·2	95	90·7	94·8	90·3	94·6	89·75	94·4
5	85·5	91·25	83·9	91·45	83	91	81·8	90·4	80·7	89·8
6	75	86·7	71	84·5	69	83·5	67·5	82	65·5	80·8
7	69·6	77·4	53	72·1	49	69·7	46·9	67·9	44·2	65·7
8	42	63·7	31·7	54·7	26·8	50	24·4	39·6	21·5	43·8
9	29	52·2	15	34	10·9	28·1	9·8	25·1	9	21·9
10	12·3	29·2	5·65	15	4·6	12·3	4·25	10·55	3·7	9·9
11	7·5	19	3·45	8·6	3·2	6·15	2·05	5	1·65	4·1
12	5·6	14·4	2·7	6·8	1·65	4·05	1·10	2·75	0·8	2·05
13	4·75	12·65	2·3	5·8	1·30	3·2	0·8	2·2	0·5	1·2
14	4·40	11·85	2·2	5·6	1·2	2·9	0·69	1·6	0·35	1

TABLE 64

Nitrogen and Argon

Nitrogen-content of liquid and vapour on each plate in *boiling-columns* when the heat-expenditure C_a ranges from 15,000 to 1,000,000 kg. cal. for 100 kg. liquid argon run off at the base.

No. of plate from base.	Heat-expenditure C_a for 100 kg. argon.									
	15,000 kg. cal.		40,000 kg. cal.		90,000 kg. cal.		800,000 kg. cal.		1,000,000 kg. cal.	
	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %
12	—	—	—	—	90	94·5	97·7	98·5	97·7	98·5
11	—	—	—	—	89·2	94·3	96·9	98·2	97·1	98·4
10	—	—	80	90	88	93·6	95·4	97·4	95·5	97·5
9	57·7	75·7	76·6	87·7	85·6	92·6	92·4	95·8	92·5	95·9
8	53·7	72·5	70·6	84·2	80·1	89·6	86·7	92·8	87·6	93·3
7	43·8	64·9	60·7	77	69·6	83·5	75·8	87·1	77·2	88
6	33·6	56·9	44·1	67·3	53·9	72·9	58·5	76·1	60·75	77·5
5	20·55	43·7	28·3	51·3	33·1	56·1	36·2	58·8	38·6	61
4	10·1	26·3	14	31·2	15·9	34·4	17	36·3	18·1	38·9
3	7·2	12·8	7·18	15·3	7·15	16·5	7·18	17·8	7·19	18·1
2	2·78	6·6	2·77	6·75	2·80	6·82	2·85	7	2·85	7·1
1	1	2·5	1·15	2·8	1·19	2·95	1·25	3·05	1·25	3·15
	0·5	1·25	0·5	1·25	6·5	1·25	0·5	1·25	0·5	1·25

TABLE 65 (CHART XV)

Water and Nitric Acid

$\alpha = 525$
$\beta = 110$

Water-content of liquid mixtures of water and nitric acid and of the vapours arising therefrom. Ratios of liquids $\frac{s}{w} = f$, and of vapours $\frac{s_d}{w_d} = f_d$. Values of $\frac{\alpha + f\beta}{f - f_d}$ and $\frac{\alpha + f_d\beta}{f - f_d}$.

Water in liquid wt. %	f	Water in vapour wt. %	f_d	$\frac{\alpha + f\beta}{f - f_d}$	$\frac{\alpha + f_d\beta}{f - f_d}$
99	0·0101	99·97	0·001	58,300	58,200
98	0·0204	99·94	0·0012	27,450	27,350
97	0·031	99·91	0·0014	17,840	17,740
96	0·042	99·88	0·0016	15,590	15,500
95	0·053	99·85	0·0018	10,350	10,230
94	0·064	99·82	0·002	8,560	8,450
93	0·075	99·79	0·0023	7,350	7,240
92	0·087	99·76	0·0025	6,300	6,190
91	0·099	99·73	0·0028	5,570	5,460
90	0·111	99·70	0·003	4,981	4,861
89	0·124	99·67	0·0033	4,462	4,347
88	0·136	99·64	0·0036	4,087	3,974
87	0·149	99·61	0·004	3,727	3,617
86	0·163	99·58	0·0043	3,426	3,312
85	0·176	99·55	0·0046	3,176	3,066
84	0·190	99·52	0·005	2,948	2,835
83	0·205	99·49	0·005	2,740	2,630
82	0·219	99·46	0·006	2,574	2,466
81	0·234	99·31	0·007	2,424	2,314
80	0·250	99·16	0·009	2,289	2,177
79	0·266	99·01	0·010	2,160	2,051
78	0·282	98·89	0·012	2,057	1,946
77	0·298	98·70	0·013	1,947	1,835
76	0·316	98·37	0·017	1,870	1,760
75	0·333	98·04	0·020	1,792	1,681
74	0·351	97·71	0·024	1,720	1,607
73	0·369	97·38	0·027	1,652	1,541
72	0·388	97·05	0·030	1,584	1,473
71	0·408	96·72	0·034	1,521	1,412
70	0·428	96·40	0·037	1,458	1,348
69	0·449	95·96	0·042	1,406	1,298
68	0·470	95·52	0·047	1,361	1,250

Water in liquid wt. %	f	Water in vapour wt. %	f_d	$\frac{a + f\beta}{f - f_d}$	$\frac{a + f_d\beta}{f - f_d}$
67	0·492	95·08	0·052	1,314	1,205
66	0·515	94·64	0·057	1,268	1,157
65	0·538	94·20	0·062	1,226	1,117
64	0·562	93·56	0·069	1,185	1,076
63	0·587	92·92	0·076	1,150	1,039
62	0·613	92·28	0·084	1,118	1,009
61	0·639	91·64	0·091	1,082	973
60	0·667	91·00	0·099	1,052	943
59	0·695	90·14	0·109	1,021	912
58	0·724	89·28	0·122	1,004	893
57	0·754	88·42	0·131	972	862
56	0·786	87·56	0·142	947	838
55	0·818	86·70	0·153	922	813
54	0·852	85·70	0·167	897	787
53	0·886	84·40	0·185	883	773
52	0·923	83·10	0·203	863	754
51	0·961	81·80	0·222	851	741
50	1·000	80·50	0·242	831	723
49	1·041	78·75	0·270	824	715
48	1·083	77·00	0·298	816	708
47	1·127	75·25	0·329	811	701
46	1·174	73·50	0·360	796	689
45	1·222	71·75	0·393	790	681
44	1·273	70·00	0·428	790	680
43	1·326	67·50	0·481	791	682
42	1·391	65·00	0·538	792	683
41	1·439	62·50	0·600	812	703
40	1·500	60,00	0·666	828	717
39	1·564	55·60	0·798	904	796
38	1·631	51·20	0·953	1,034	926
37	1·703	46·80	1·137	1,260	1,150
36	1·777	42·40	1·358	1,718	1,610
35	1·857	38·00	1·631	3,222	3,111
34	1·941	36·00	1·777	4,501	4,392
33	2·030	34·00	1·941	8,370	8,260
32·5	2·077	33·00	2·030	16,030	15,930
32	2·125	32·00	2·125	—	—

TABLE 66

Water and Nitric Acid

Reflux heat C_R required in *rectifying columns* to separate 1 kg. water as vapour of 99·97, 98, 97% from mixtures of water and nitric acid containing 98—33% water.

Water-content.		Kg. cal. needed to produce 1 kg. water as vapour of		
Liquid wt. %	Vapour wt. %	99·7%	98%	97%
98	99·94	5·5	—	—
96	99·88	9·3	—	—
94	99·82	8·56	—	—
92	99·76	9·60	—	—
90	99·70	9·90	—	—
88	99·64	10·7	—	—
86	99·58	11·22	—	—
84	99·52	11·8	—	—
82	99·46	12·8	—	—
80	99·16	18·3	—	—
78	98·86	22·6	—	—
76	98·37	29·9	—	—
74	97·71	39·7	6·88	—
72	97·05	45·8	15·84	—
70	96·4	52·5	24·60	10·1
68	95·52	62·5	36·70	23·1
66	94·64	71·1	46·9	34·2
64	93·55	80·2	57·8	46·0
62	92·28	92·9	71·6	60·4
60	91·0	101·9	82·9	72·4
58	89·28	121·0	108·0	98·0
56	87·56	133·5	115·5	106·0
54	85·7	148·9	131·8	122·8
52	83·1	174·3	157·9	149·2
50	80·5	200·2	184·4	176·1
48	77·0	242·3	226·8	218·6
46	73·5	285·7	270·6	262·6
44	70·0	309·6	322·3	314·4
42	65·0	380·1	410·2	402·3
40	60·0	550·6	534·8	526·6
39	55·6	718·0	707·0	698·0
38	51·2	980·0	960·0	950·0
37	46·8	1420·0	1412·0	1395·0
36	42·4	2330·0	2320·0	2280·0
35	38·0	5240·0	5188·0	5152·0
34	36·0	8010·0	7900·0	7870·0
33	34·0	16230·0	16100·0	16000·0

TABLE 67

Water and Nitric Acid

Water-content of liquid and vapour on each plate in *rectifying columns* when vapour containing 99·97% water (0·03% nitric acid) is produced with a heat-expenditure C_R ranging from 1,000 to 170,000 kg. cal. for 10 kg. water.

No. of plate from top.	Reflux-heat C_R for 10 kg. water.									
	1,000 kg. cal.		1,500 kg. cal.		2,000 kg. cal.		2,500 kg. cal.		5,000 kg. cal	
	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %
	99·0	99·97	99·0	99·97	99·0	99·97	99·0	99·97	99·0	99·97
1	92·5	99·77	90·0	99·7	87·8	99·63	87·5	99·6	83·3	99·5
2	76·9	98·7	74·0	97·6	70·7	96·6	68·75	95·7	60·6	91·25
3	68·5	95·58	63·45	93·27	59·35	90·25	56·65	87·85	48·0	77·1
4	64·1	93·6	58·8	90·6	53·5	85·2	51·5	82·0	43·3	67·85
5	62·5	92·4	56·2	87·3	51·25	82·5	49·25	78·85	41·7	64·10
6	61·5	91·9	55·0	86·5	50·5	80·3	48·0	77·5	41·18	62·65
7	60·2	91·6	54·5	86·0	50·5	80·2	46·95	76·75	40·9	62·3
8	—	—	—	—	—	—	47·15	76·0	40·8	62·25

No. of plate from top.	Reflux-heat C_R for 10 kg. water.									
	10,000 kg. cal.		25,000 kg. cal.		50,000 kg. cal.		100,000 kg. cal.		170,000 kg. cal.	
	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %
	99·0	99·97	99·0	99·97	99·0	99·97	99·0	99·97	99·0	99·97
1	81·6	99·31	80·5	99·25	80·0	99·20	79·55	99·18	79·35	99·16
2	56·1	87·3	52·6	83·45	51·0	81·55	50·0	80·33	59·99	79·9
3	42·9	67·3	39·5	58·1	39·2	54·0	38·45	51·5	37·7	50·9
4	39·0	55·7	36·9	45·6	36·0	42·35	35·5	40·1	35·6	38·7
5	38·3	52·1	36·2	42·9	35·4	38·5	34·5	37·1	34·4	36·7
6	38·1	51·4	35·7	42·3	35·2	38·5	34·1	36·2	33·7	35·4
7	38·0	51·2	35·2	42·0	—	—	33·9	35·8	33·3	34·7
8	—	—	—	—	—	—	—	—	33·2	34·2

TABLE 68

Water and Nitric Acid

Water-content of liquid and vapour on each plate of *boiling-columns* when the heat-expenditure C_a ranges from 80,000 to 1,500,000 kg. cal. for 100 kg. nitric acid run off at base.

No. of plate from base.	Heat-expenditure C_a for 100 kg. nitric acid.									
	80,000 kg. cal.		90,000 kg. cal.		100,000 kg. cal.		120,000 kg. cal.		150,000 kg. cal.	
	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %
7	53·0	84·4	57·7	89·2	—	—	—	—	72·25	97·25
6	52·0	83·1	57·0	88·5	59·0	90·8	63·2	93·0	71·8	96·9
5	50·3	81·0	55·2	86·9	56·65	88·1	56·95	88·4	69·61	96·1
4	48·1	77·05	52·1	83·2	51·15	82·15	48·25	77·45	61·9	92·25
3	45·8	73·15	48·0	77·0	44·9	71·9	41·5	63·15	50·0	80·3
2	43·3	68·3	43·6	69·05	40·4	61·1	38·35	52·9	40·5	61·25
1	41·41	63·5	40·4	61·3	38·6	53·9	37·4	48·2	37·5	48·9
	40·0	60·0	39·0	55·6	38·0	51·2	37·0	46·8	36·5	44·6

No. of plate from base.	Heat-expenditure C_R for 100 kg. nitric acid.									
	180,000 kg. cal.		350,000 kg. cal.		500,000 kg. cal.		900,000 kg. cal.		1,500,000 kg. cal.	
	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %	Liq. %	Vap. %
10	—	—	—	—	—	—	94·4	99·8	—	—
9	—	—	—	—	—	—	93·3	99·75	—	—
8	—	—	—	—	—	—	76·8	98·6	—	—
7	—	—	—	—	90·1	99·8	50·0	80·6	96·6	99·85
6	75·5	98·2	87·0	99·6	86·45	99·8	38·3	52·1	84·4	99·55
5	71·7	96·95	84·6	99·56	67·23	99·5	35·4	39·4	76·5	98·5
4	60·35	91·2	74·0	97·6	45·65	72·6	34·25	36·5	49·0	78·7
3	46·5	74·35	52·5	83·9	38·0	51·2	33·6	35·3	37·8	50·0
2	38·85	55·3	39·15	57·6	35·5	40·1	33·3	34·5	34·9	38·0
1	36·6	45·3	38·1	42·6	34·3	36·5	33·2	34·2	33·4	34·9
	36·0	42·4	35·0	38·0	34·0	36·0	33·0	34·0	33·0	34·0

PART IV

CHARTS

CHART I (TABLE 1)

Vapour-Composition Curves.

Percentage weights of low-boiling component in the vapours from various binary liquid mixtures.

(The low-boiling component is underlined.)

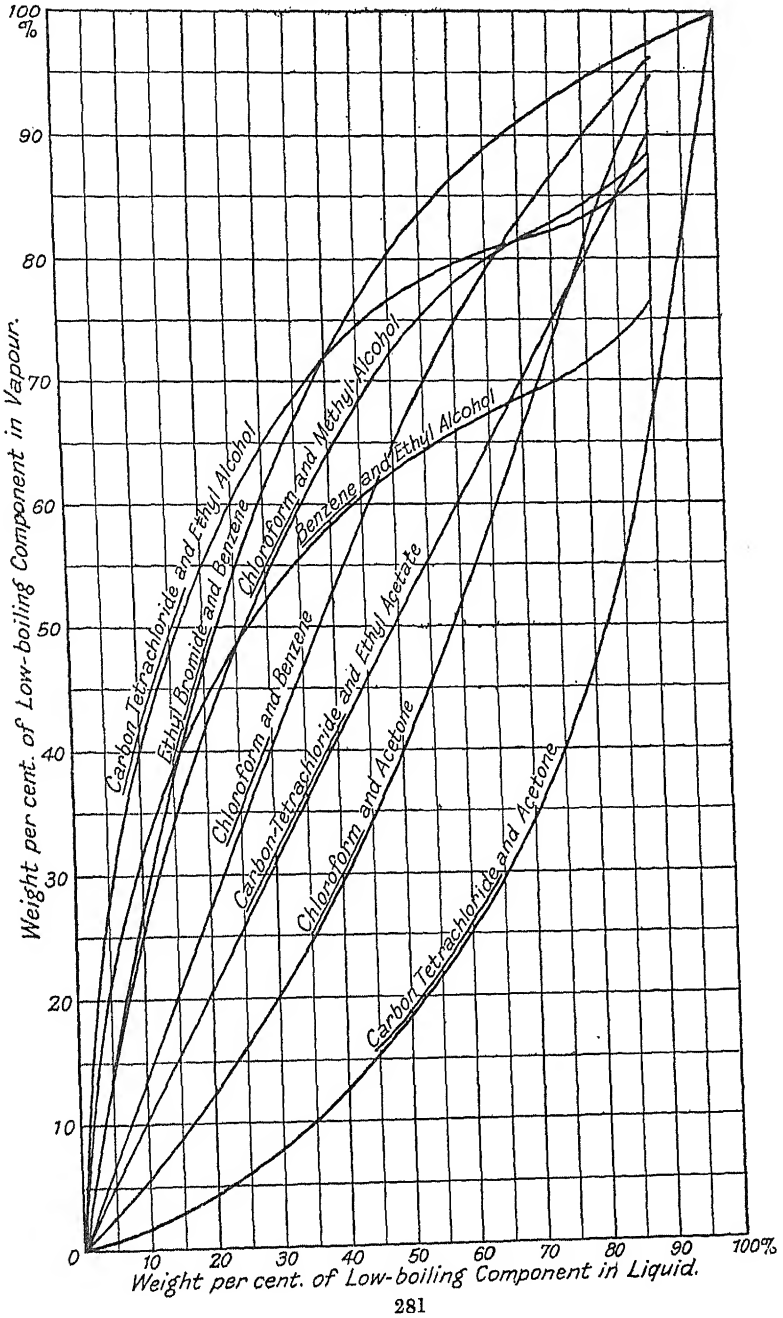


CHART II (Tables 21, 22, 28, 29)

Ethyl Alcohol and Water. Methyl Alcohol and Water.

Gradual condensation of vapour containing initially 60% alcohol. Gradual vaporisation of liquids containing initially 50, 40, 30, 20, 10% alcohol.

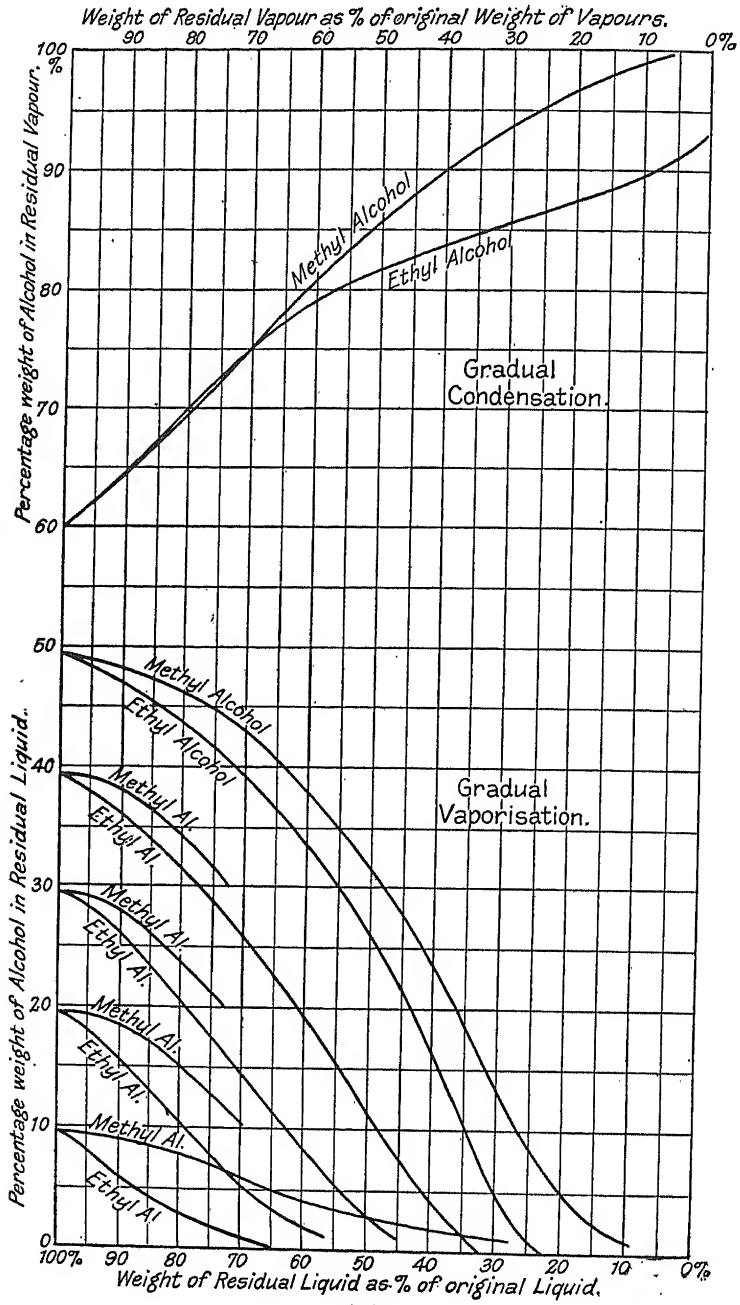


CHART III (Tables 2, 23, 30, 42, 46, 51)

Percentage weights of Ethyl Alcohol–Methyl Alcohol–Acetone–Acetic Acid–Formic Acid–Ammonia in the vapour evolved from liquid aqueous mixtures of these substances.

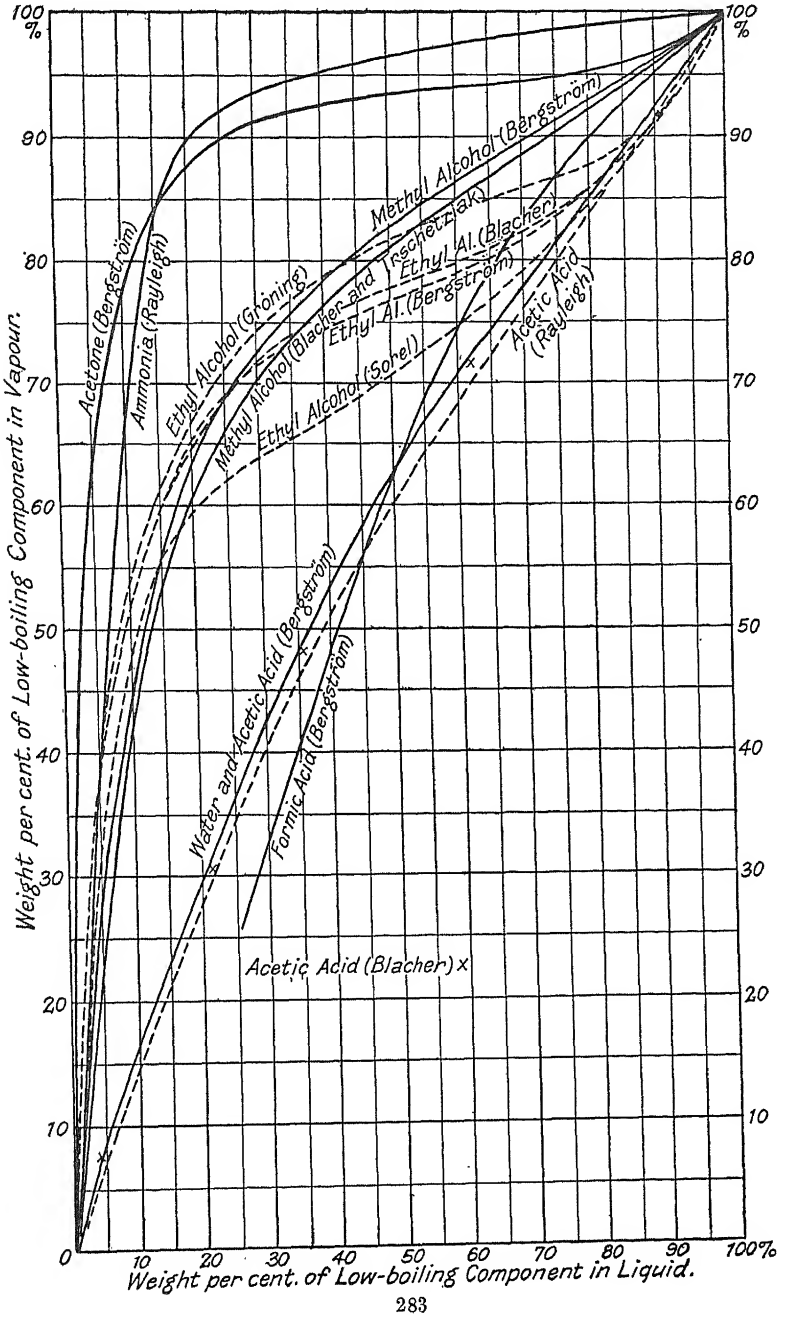


CHART IV

Ethyl Alcohol and Water.

Two charges, 5000 and 10,000 kg., containing 50%. After vaporisation of proportional weights of alcohol (100 and 200 kg. in 1 hour, in this case), the residual liquids have the same alcohol-content.

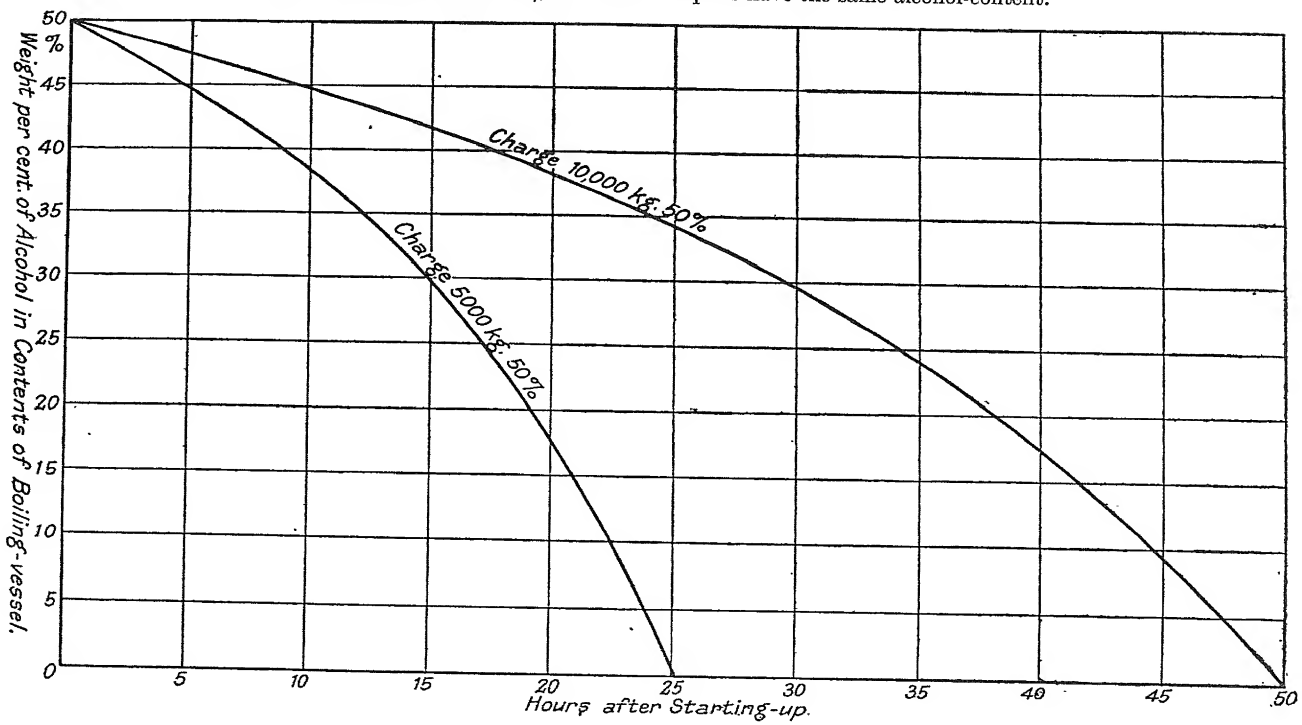


CHART V (Tables 11, 18, 24, 43)

Ethyl Alcohol, Methyl Alcohol, Acetic Acid and Water.

Reflux heat C_R required to separate 1 kg. of low-boiling component (ethyl alc., methyl alc., water, of 85·6–99%) from vapour-mixtures (of 0·5–93%).
(b) Heat C_a required to separate 10 kg. high-boiling component (water or acetic acid) from these mixtures.

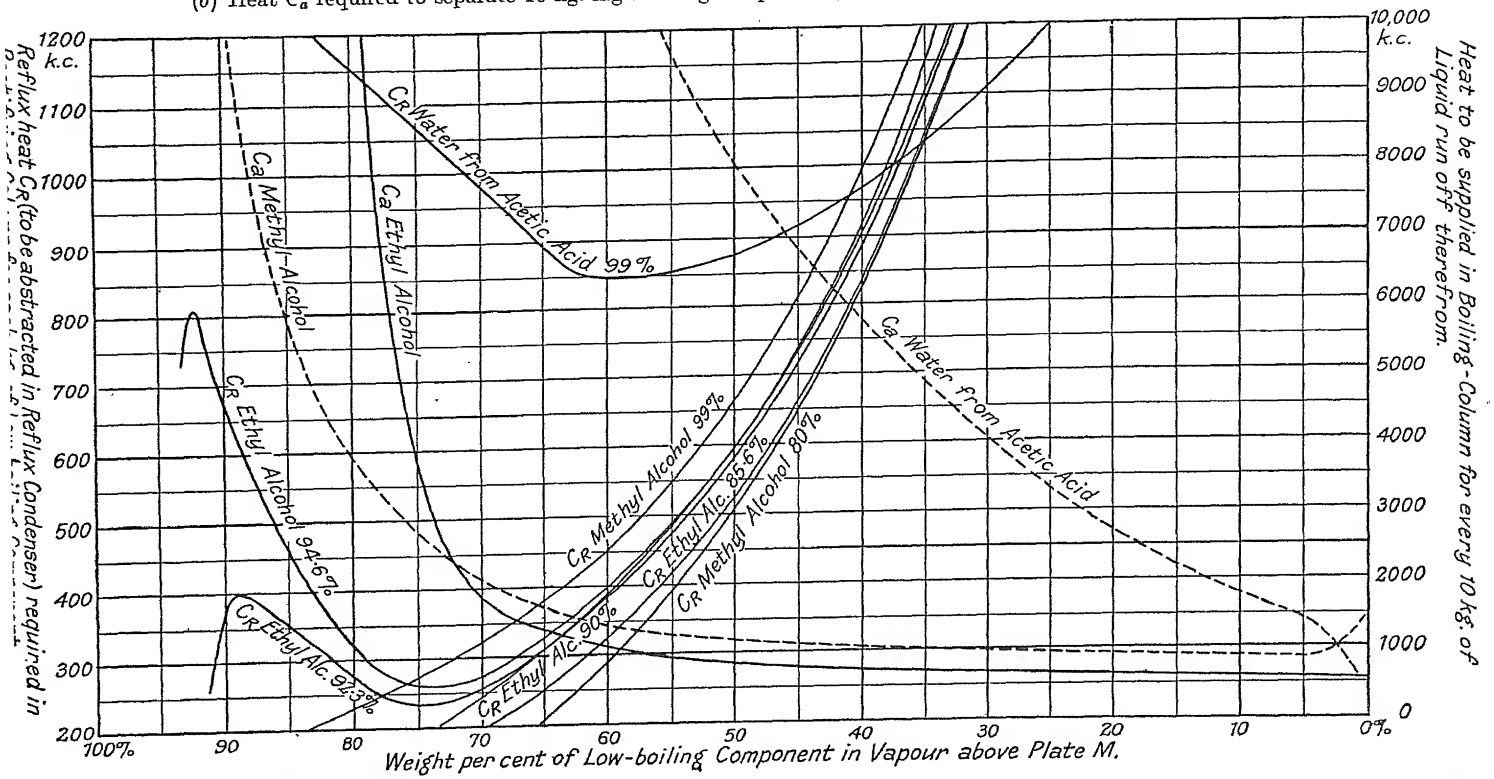


CHART VI (Tables 12, 13, 14)

Ethyl Alcohol and Water.

Ethyl-alcohol content of the vapours which ascend from each plate in rectifying columns when for every 10 kg. alcohol (85·75, 92·46, 94·60%) 5000–60,000 kg.-cal. of reflux heat are abstracted in the reflux condenser.

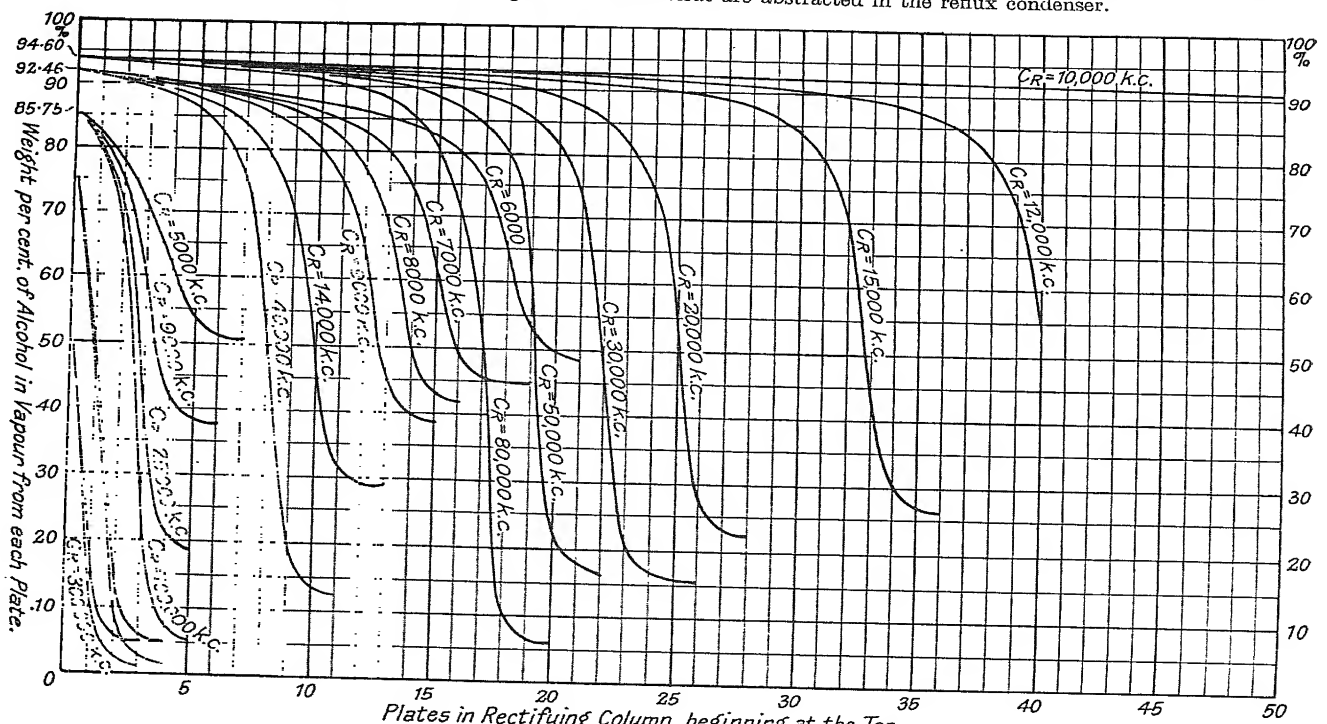


CHART VII (TABLE 19)

Ethyl Alcohol and Water.

Percentage weight of alcohol in the vapours which ascend from each plate in boiling-columns, when for every 100 kg. spent wash ($w - w_e$) 7000–450,000 kg. cal. are passed in at the base.

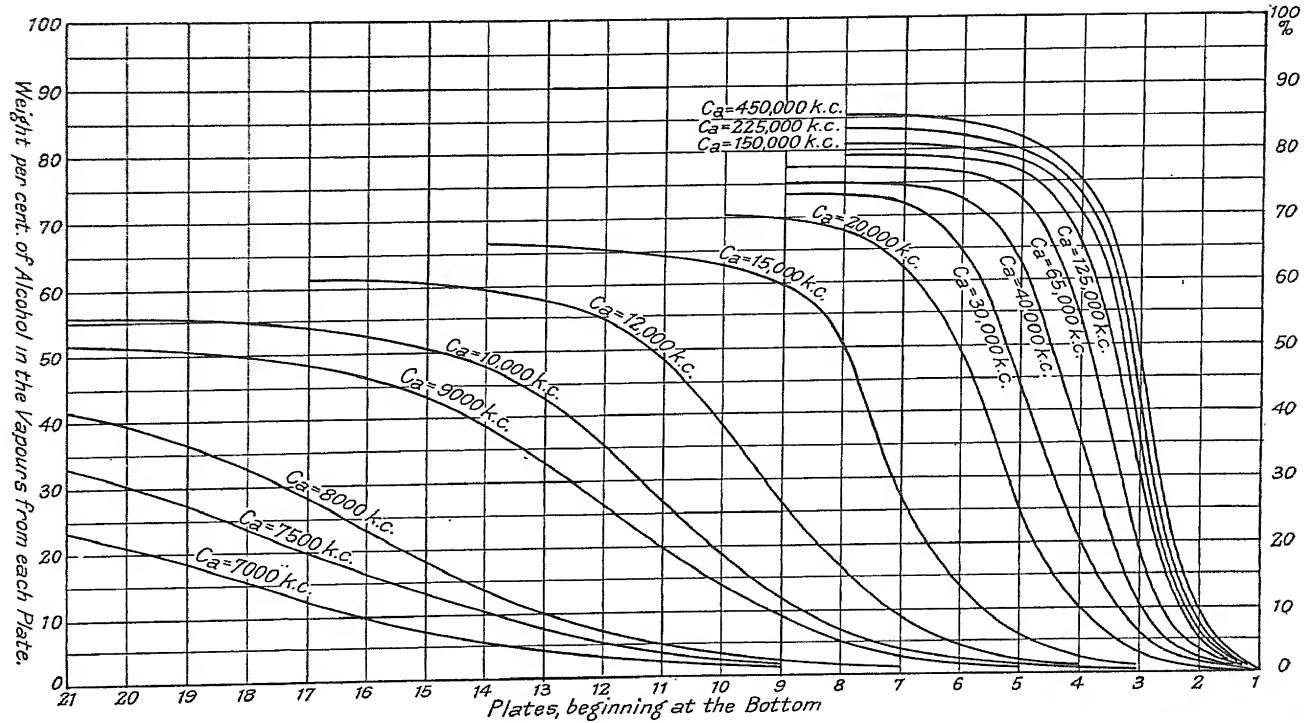


CHART VIII (TABLE 20)

Ethyl Alcohol and Water.

Alcohol-content of liquid on the plate of entry *M* into the boiling-column when from 0 up to 10,000 kg.-cal. (C_h) are passed in for every 100 kg. of alcohol-water mixture containing 0·5–80% wt. alcohol.

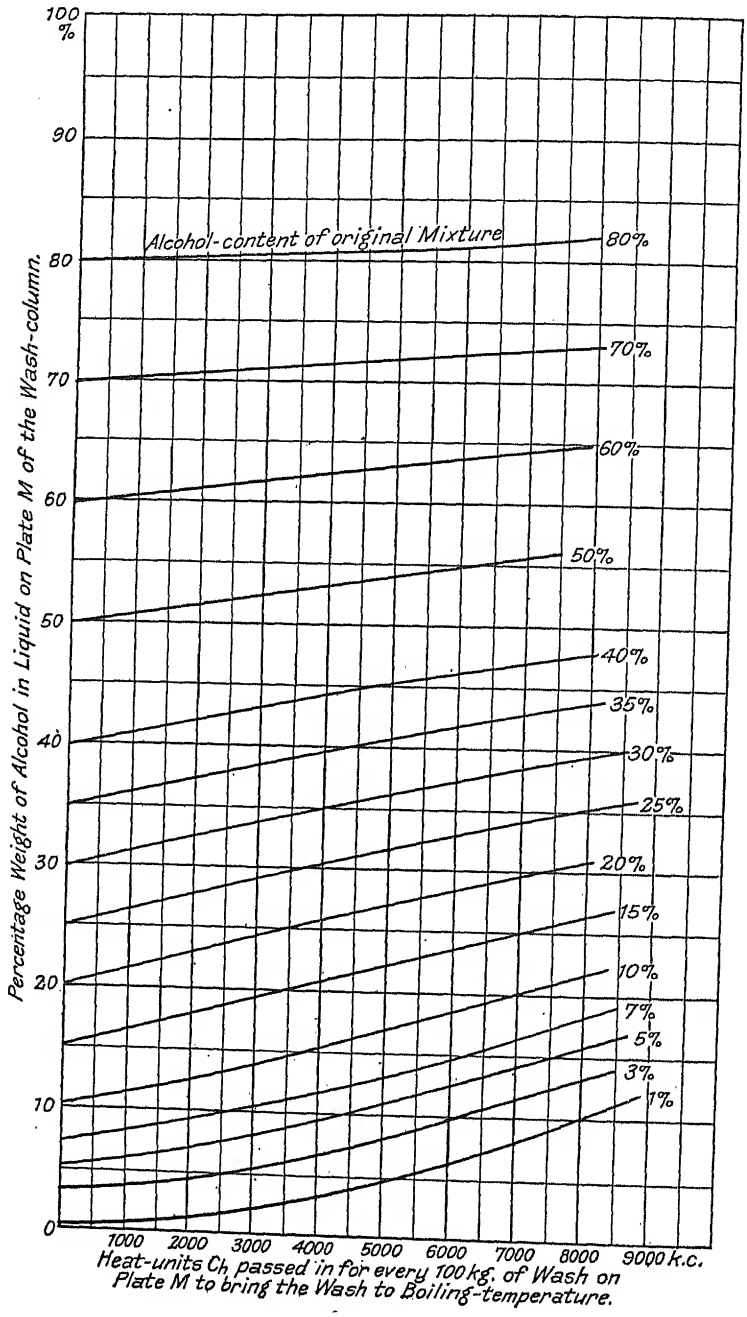


CHART IX

Ethyl Alcohol and Water.

Alcohol-content of vapour from plates I–XV of the rectifying column and from plates 1–17 of the boiling-column, when for every 10 kg. alcohol C_R kg.-cal. are abstracted and for every 100 kg. spent wash C_a kg.-cal. are introduced.

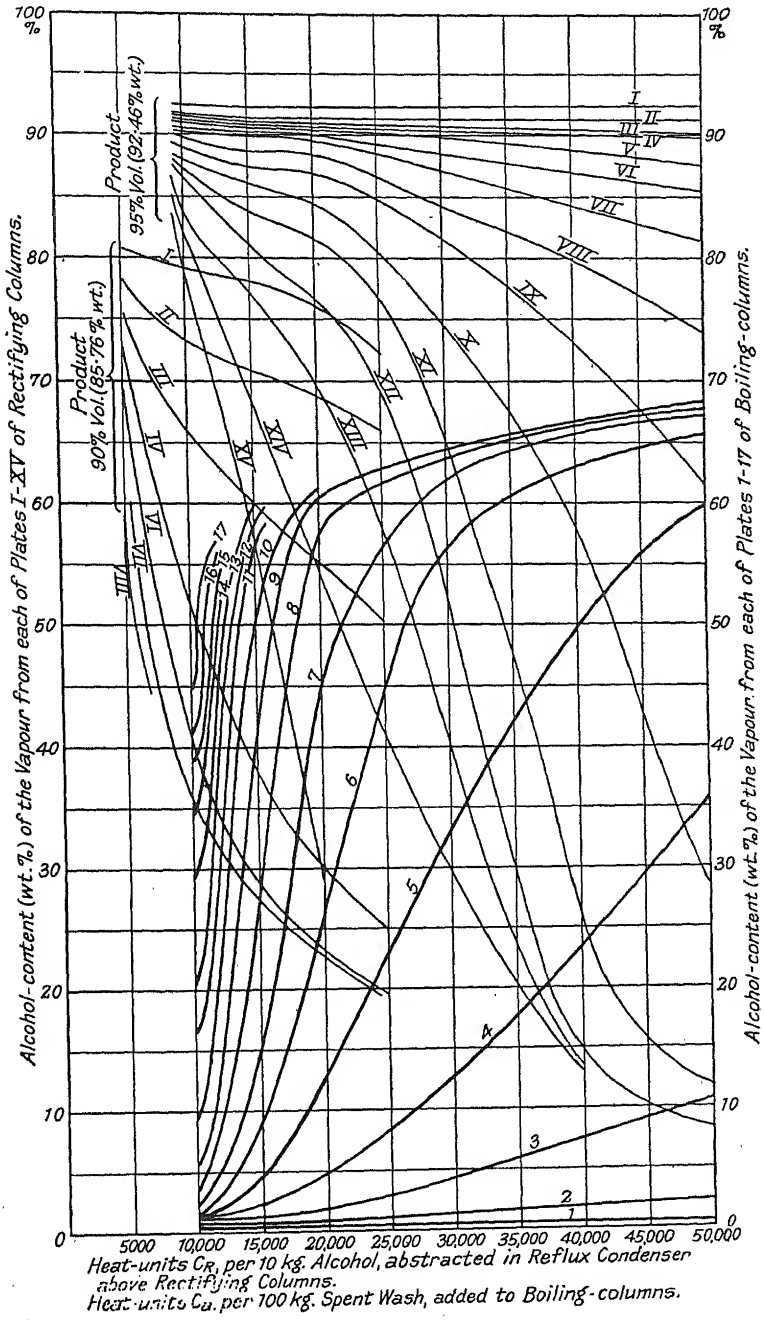


CHART X (TABLE 25)

Methyl Alcohol and Water.

Methyl-alcohol content of the vapours ascending from each plate in rectifying columns, when 10,000–250,000 kg. cal. are abstracted in the reflux condenser for every 10 kg. of 99% methyl alcohol produced.

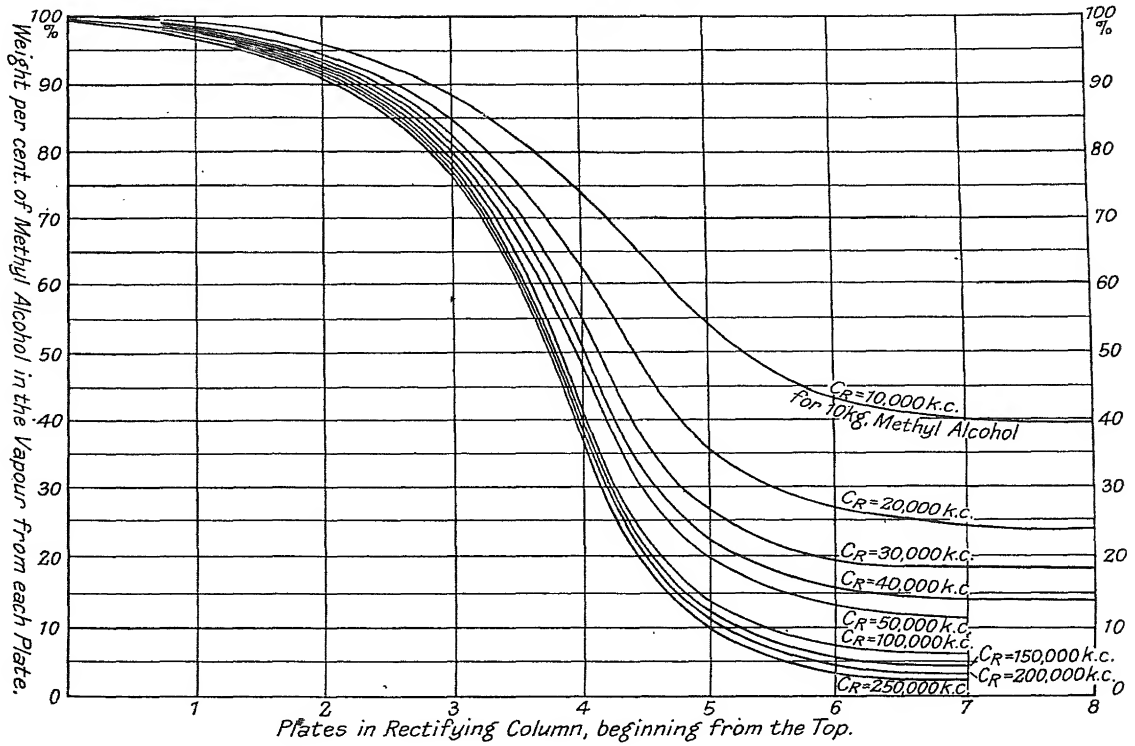
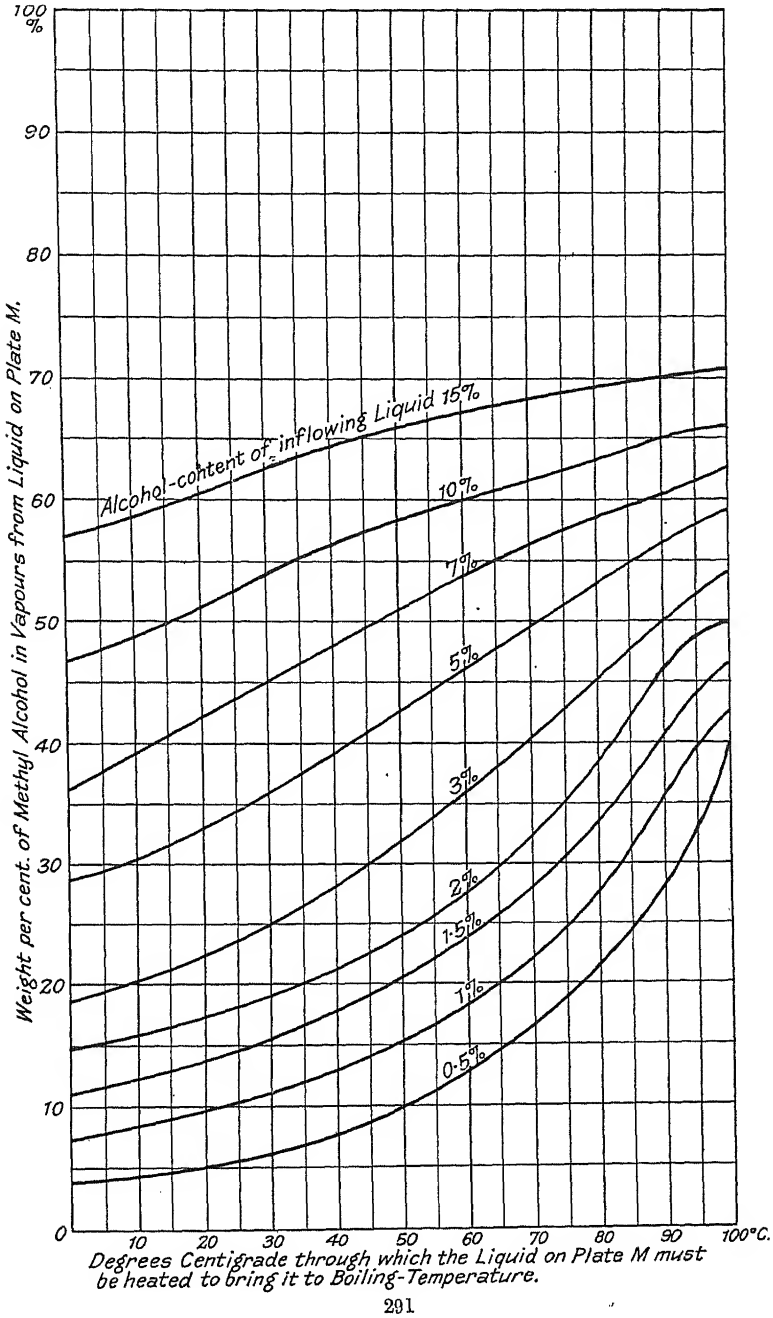


CHART XI (TABLE 26)

Highest [illegible] content (in wt.%) of the vapours from 0·5–15% mixtures of [illegible] and water when these vapours reach plate *M* of distilling columns at temperatures 0°–90° below boiling-temperature.



Methyl Alcohol and Water.

Methyl-alcohol content (in wt.%) of the vapours ascending from each plate in boiling-columns, when for every 100 kg. exhausted liquid $(w - w_e)$ 14,000–100,000 kg. cal. (C_a) are introduced at the base.

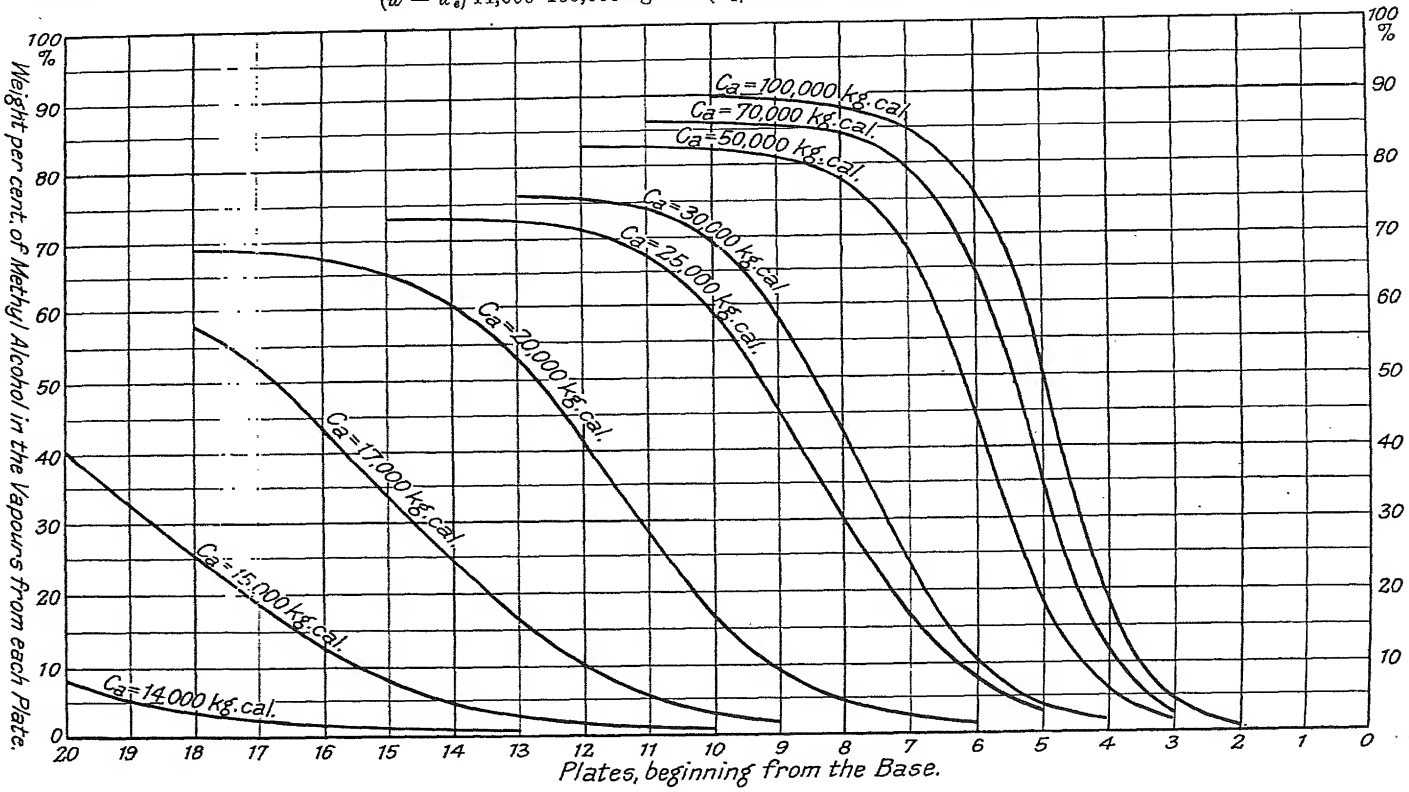
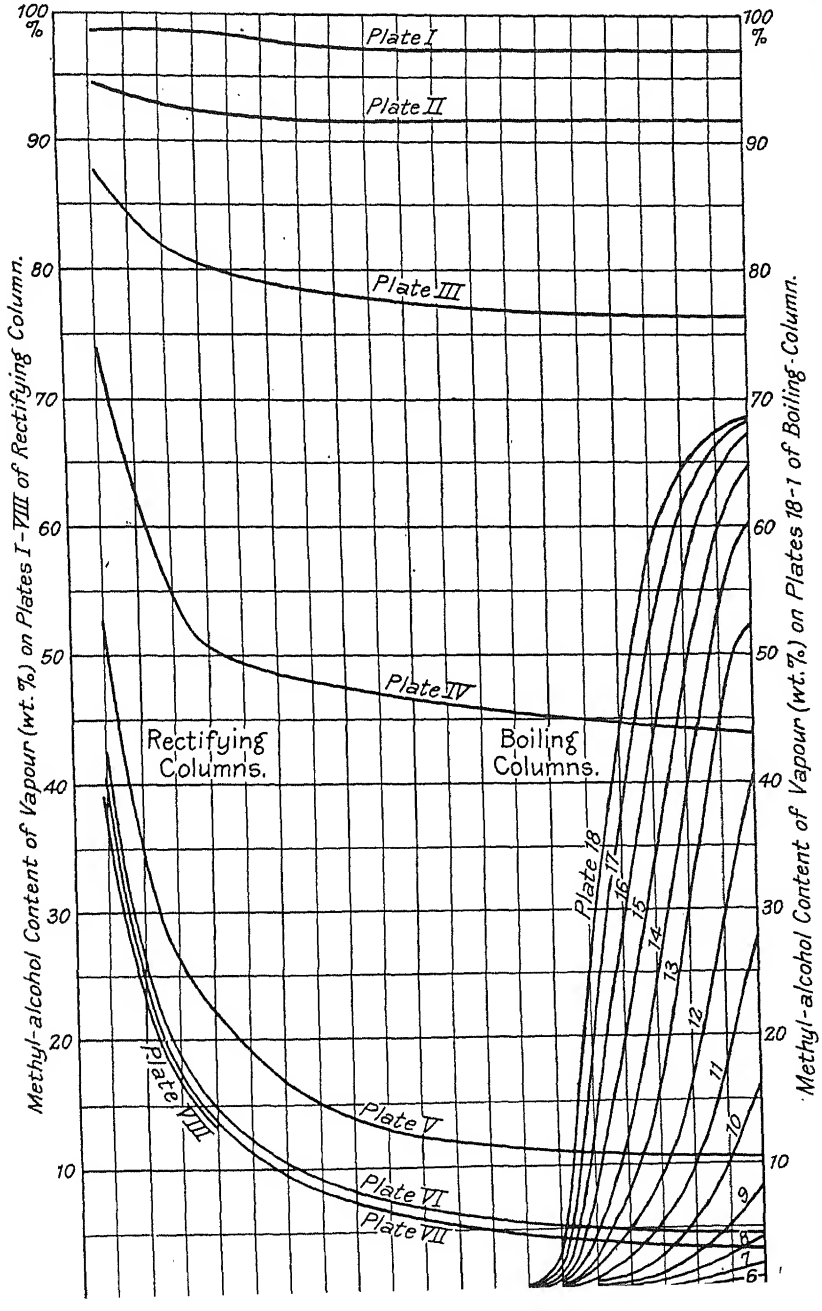


CHART XIII (Tables 25, 27)

Methyl Alcohol and Water.

Methyl-alcohol content of vapours on each of the plates I–VIII of rectifying columns, and on each of the plates 18–1 of boiling-columns, when the heat-units C_R, given by the abscissæ, and referring to 1 kg. alcohol, are abstracted in the reflux condenser: and when the heat units C_a, for every 100 kg. spent liquor, are used in the boiling-column.



Reflux heat C_R required in rectifying column to produce 1 kg. or 10 kg. of low-boiling component as 20–99·75% product from weaker vapours. Heat C_a required to separate 1 or 10 kg. high-boiling component.

Acetone and Water (Table 31), Acetone and Methyl Alcohol (Table 35). Formic Acid and Water (Tables 47, 48), Ammonia and Water (Table 52), Nitrogen and Oxygen (Table 58).

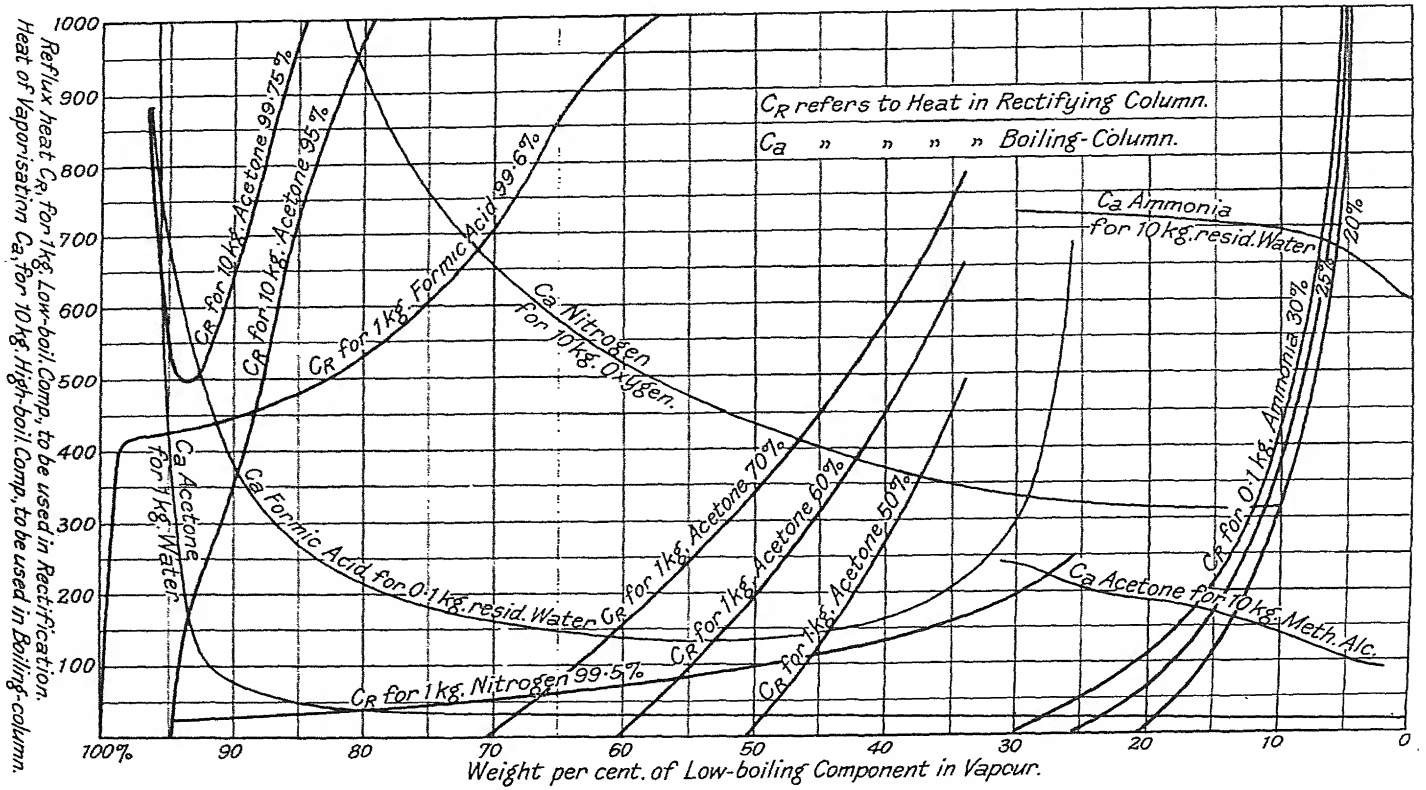


CHART XV

Acetone-content (wt.%) of vapour from acetone–methyl-alcohol mixtures: Nitrogen-content of vapour from nitrogen–oxygen mixtures: Water-content of vapour from nitric-acid–water mixtures. According to Pettit, Bergström, and Baly.

Acetone and Methyl Alcohol (Table 34), Nitrogen and Oxygen (Table 57), Water and Nitric Acid (Table 65).

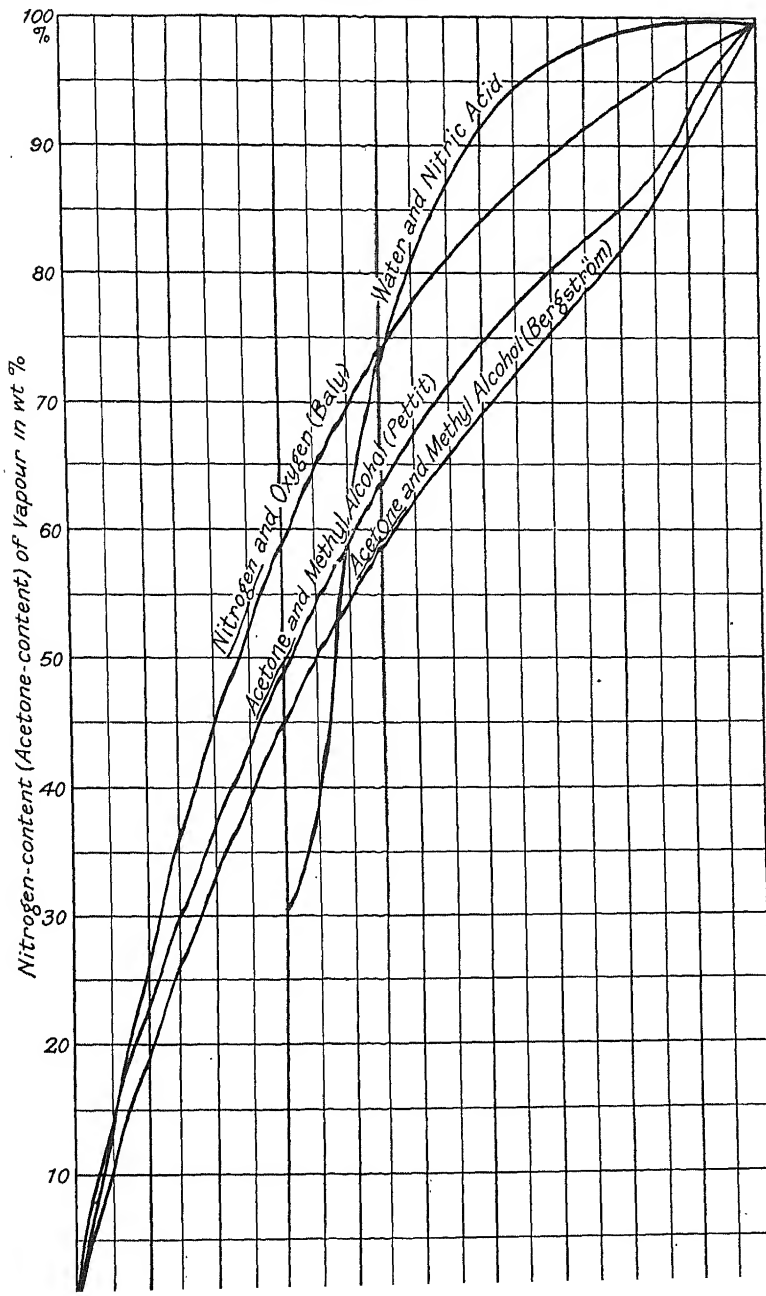
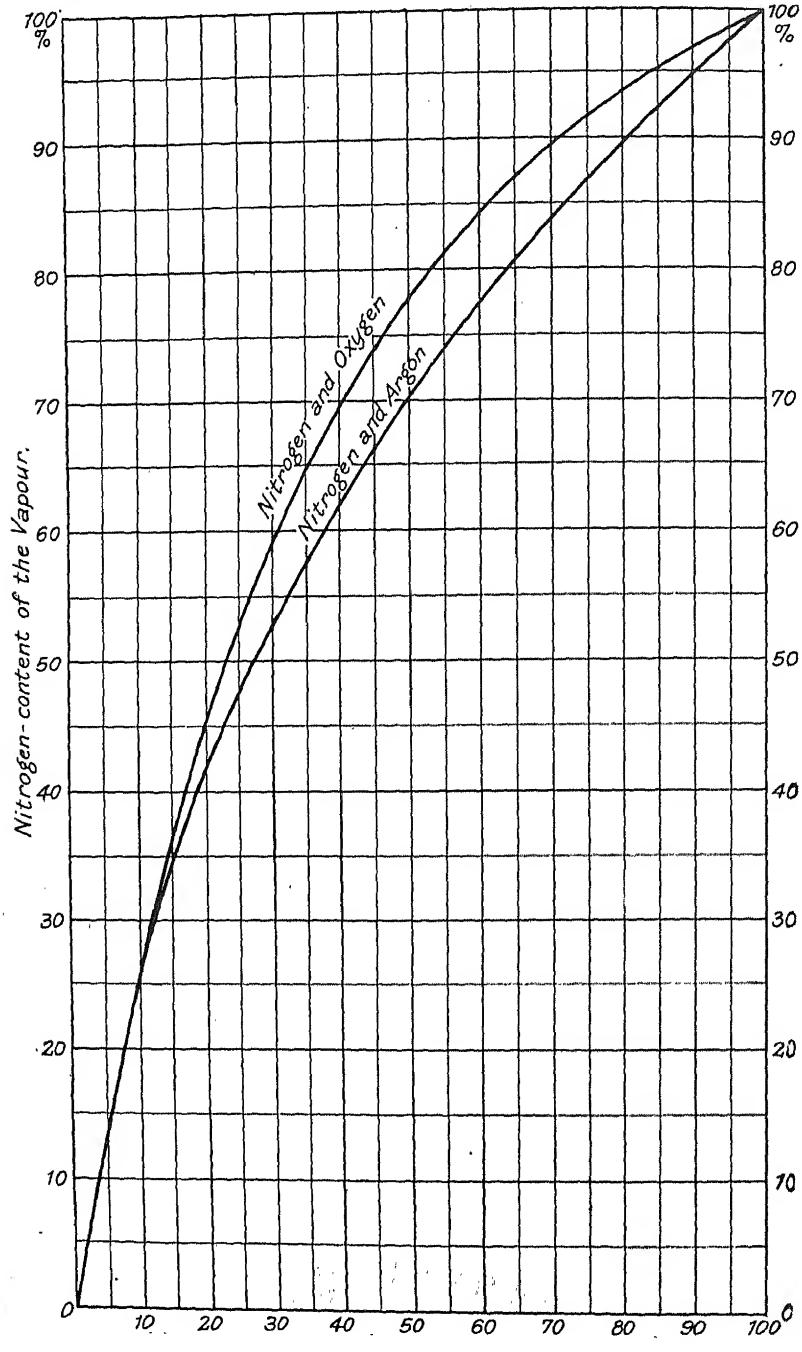


CHART XVI (Tables 57, 61)

Nitrogen and Oxygen. Nitrogen and Argon.

Nitrogen-content (wt.%) of the vapour rising from liquid mixtures of nitrogen and oxygen (Baly).



INDEX

Numbers of pages given in italics refer to the Tables in Part III. References to the individual Charts will be found in the text.